EFFECTS OF OSCILLATION FREQUENCY AND AMPLITUDE ON SEPARATION IN AN UNSTEADY TURBULENT FLOW

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THESIS

EFFECTS OF OSCILLATION FREQUENCY
AND AMPLITUDE ON SEPARATION IN
AN UNSTEADY TURBULENT FLOW

by

Martin Fox

September, 1980

Thesis Advisor: J. A. Miller

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A two-dimensional model was developed and used in a preliminary investigation of the relationship between flow oscillation frequency, oscillation amplitude, and turbulent boundary layer separation in a low speed, oscillating wind tunnel.

It was found that the frequency of oscillation had a profound effect upon the amplitude of oscillation and flow separation. Frequencies from 20 Hz to 28 Hz and 70 Hz to 80 Hz

20. ABSTRACT (continued)

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Effects of Oscillation Frequency and Amplitude on Separation in an Unsteady Turbulent Flow

by

Martin Fox
Lieutenant, United States Navy
B.S.A.E., Auburn University, 1973

Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

A two-dimensional model was developed and used in a preliminary investigation of the relationship between flow oscillation frequency, oscillation amplitude, and turbulent boundary layer separation in a low speed, oscillating wind tunnel.

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LIST OF SYMBOLS

c	model chord length (inches)
C_P	nondimensional coefficient of pressure - $C_P = \dfrac{p - p_o}{\frac{1}{2}\rho\bar{U}^2}$
f	flow oscillation frequency - Hertz (Hz)
N_A	nondimensional flow oscillation amplitude - $N_A = \dfrac{\Delta u}{\bar{U}}$
p	static pressure (lbf/ft^2)
p_o	freestream ambient pressure (lbf/ft^2)
q	test section dynamic pressure (lbf/ft^2) $q = \frac{1}{2}\rho\bar{U}^2$
T	freestream ambient temperature (^{o}F)
u	streamwise component of tunnel velocity (ft/sec)
Δu	velocity fluctuation (ft/sec)
$\bar{U}$	mean tunnel velocity (ft/sec)
x	streamwise model dimension taken from leading edge (inches)
x/c	normalized model location
y	dimension normal to flow (inches)
ρ	air density (lbm/ft^3)
ν	kinematic viscosity (ft^2/sec)

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I. INTRODUCTION

Increased interest in the design and development of vertical/short takeoff and landing (V/STOL) aircraft has magnified the need to fully understand the complex flow fields associated with their aerodynamic and propulsive systems. The unique capabilities of such vehicles require significant portions of their flight profiles to be performed with much of the aircraft immersed in turbulent flow. When in operation near the ground or landing platform, unsteady, turbulent flow may become the dominant phenomenon.

Given the importance of this area of study and the limitations of the analytical solutions, there is a surprisingly small body of empirical work concerned with unsteady boundary layers caused by freestream flow oscillation. This is perhaps due to a lack of suitable test facilities; that is, facilities that are capable of a wide range of freestream oscillation frequencies and amplitudes. However, significant advances were made by Karlsson [Ref. 1] who showed that flow oscillation had little effect on the mean velocity profile of the turbulent boundary layer, and Nickerson [Ref. 2] who used hot-wire anemometry in his study of the laminar boundary layer on a flat plate. Despard [Ref. 3] studied the separation of a laminar boundary layer using a flow oscillation system developed by Miller [Ref. 4]. Recently, Telionis [Ref. 5]

used hot-wire anemometry to investigate the separation and reattachment of boundary layers in unsteady conditions.

The purpose of this investigation was to develop a wind tunnel model useful in determining the effects of various flow oscillation frequencies upon the amplitude of the oscillation and their relationship, if any, to the separation of a turbulent boundary layer. It was also desired to perform initial testing on the equipment associated with a hot-wire anemometry study of the turbulent boundary layer.

II. EXPERIMENTAL EQUIPMENT

A. OSCILLATING FLOW WIND TUNNEL

1. General Description

The low-speed, oscillating flow wind tunnel located in the Aeronautics Laboratories of the Naval Postgraduate School was utilized for this study. This wind tunnel is of the open circuit design, with a 24-inch square by 223-inch long test section. The tunnel inlet is 8-feet square, resulting in a 16:1 contraction ratio. Three high solidity screens located in the inlet section upstream of the nozzle produce measured freestream turbulence intensities of from 0.261 to 0.413 per cent for the test velocities.

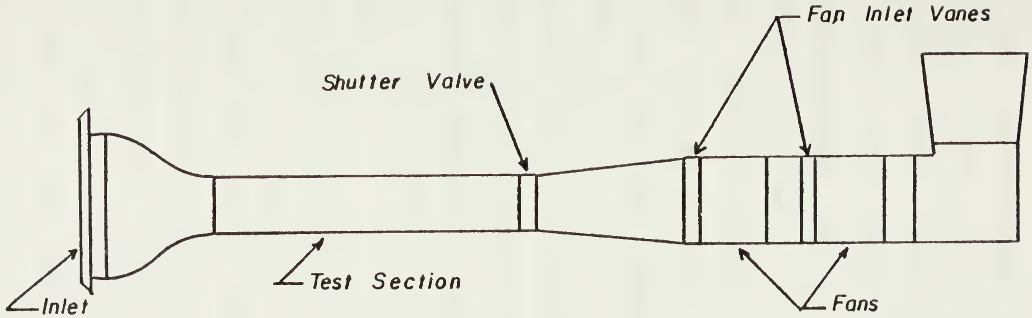
The wind tunnel drive consists of two Joy Axivane Fans in series, each of which has an internal 100 horsepower, direct connected, 1750 rpm motor. The fan blades are internally adjustable through a pitch range of 25 to 55 degrees, providing a wide operating range. Each fan has a separate set of variable inlet vanes that are multi-leaf in design and are remotely adjustable to afford fine control of test section mean velocity during tunnel operation. The tunnel velocity range is from 10 to 250 feet per second, although the maximum mean velocity used for this study was 148 feet per second. The inlet vanes are set to preswirl the air flow in the direction of fan rotation in order to

reduce fanloads. To minimize wall deflections caused by large and almost instantaneous changes in static pressure, the test section upper and lower walls are constructed of continuous pieces of two-inch thick aluminum, 24 inches wide and 223 inches in length. The test section wall facing the tunnel control console is composed of three hinged, two-inch thick, stress relieved Lucite panels. The Lucite doors, while normally secured in the closed position by twelve large bolts per panel during tunnel operation, may be hydraulically raised for access to the test section. The back wall of the test section is also composed of three panels that are manually removable in order to facilitate model installation. For this experimental study, the upstream back wall panel was made of Lucite and the two downstream panels were constructed of two-inch thick plywood to allow for instrumentation installation.

A plan view of the oscillating flow wind tunnel is shown in Figure 1. An overall photographic view of the tunnel as seen from downstream of the fan inlet vanes is shown in Figure 2.

2. <u>Flow Oscillation System</u>

A sinusoidal velocity component is introduced into the mean freestream flow by harmonic solid blockage variations downstream of the test section. This is accomplished by the use of four horizontal, rotating shutter blades that completely span the trailing edge of the test section. Four steel shafts,



PLAN VIEW OF WIND TUNNEL

FIGURE I

equidistant from each other and the test section walls, are slotted to accept various width flat blades, thereby forming a variable sized, multi-slotted, butterfly-type valve. A photographic view of the shutters looking downstream from the test section is shown in Figure 3. The use of this type of shutter system to produce flow oscillations through a large range of frequencies and amplitudes was employed by Karlsson [Ref. 1], and is identical to that employed by Miller [Ref. 4]. The drive for the shutter system is a five horsepower variable speed electric motor coupled to the bottom shaft of the shutter system via a belt and pulley system in order to produce a wide variety of frequencies. The upper three shutter shafts are connected to each other and the driven shaft by timing belts to insure that all four shutters rotate in phase. The total range of remotely selectable shutter frequencies is from 0.1 to 240 Hertz. This investigation employed frequencies of from 1 to 100 Hertz.

Gross oscillation amplitude may be changed by the installation of one of several sets of shutter blades having different widths and therefore different blockage ratios. The range of test section blockage produced by the various shutter blades was from 25 to 98 per cent. This investigation primarily utilized test section blockage of 67 and 98 per cent, resulting in amplitude variations of from 3 to 108 per cent of the mean freestream velocity. The shutters fixed in the fully open position cause a non-oscillatory blockage of approximately five per cent.

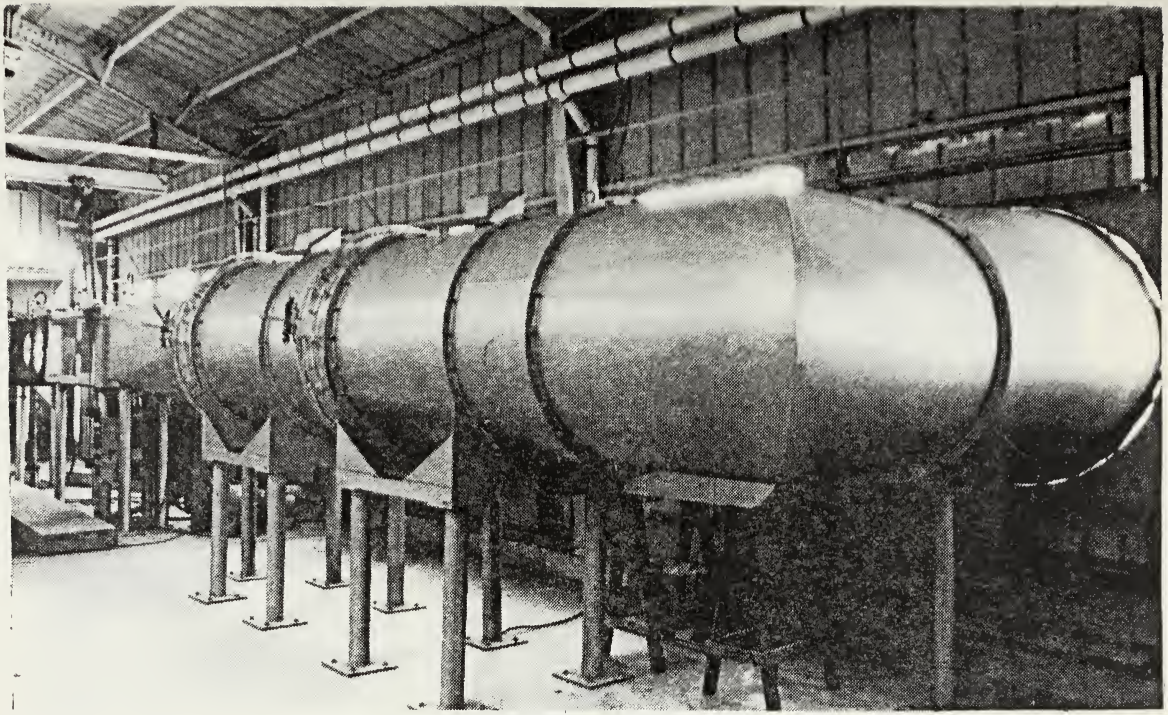


FIGURE 2

OVERALL PHOTOGRAPHIC VIEW OF THE WIND TUNNEL

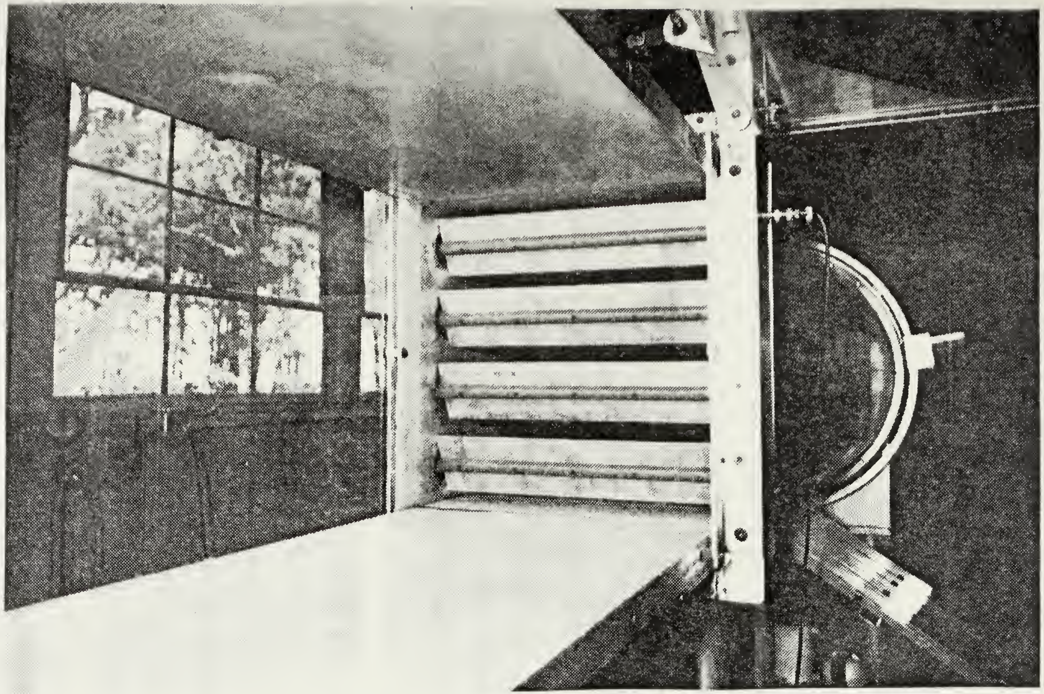


FIGURE 3

PHOTOGRAPH OF THE ROTATING SHUTTER VALVE.

B. MODELS

1. Preliminary Models

In order to effectively investigate the effects of unsteady flow on turbulent boundary layer separation, it was necessary to develop a model that would produce boundary layer separation in the neighborhood of a location in which the instrumentation could be conveniently introduced. In order to accomplish this, several possible model geometries were inexpensively constructed and tested in order to evolve a configuration to be employed on a more fully instrumented, and rugged, primary model.

The preliminary models were of all wood construction and were two-dimensional shapes spanning the width of the test section, mounted to the floor of the test section, causing convergence and divergence of the section. The models all used a 54-inch long 6-inch thick main body with provisions for interchangeable leading and trailing edge sections. Several leading/trailing edge sections were constructed with inclines of 12, 18, and 24 degrees. Figure 4 is a sketch of a preliminary model showing the main body with 24 degree leading and trailing edge sections installed. During the preliminary study, the trailing edge section was tufted for visual indications of turbulent flow and boundary layer separation.

2. Primary Model

Based on the results of the preliminary investigation, a primary model was designed.

PRELIMINARY MODEL

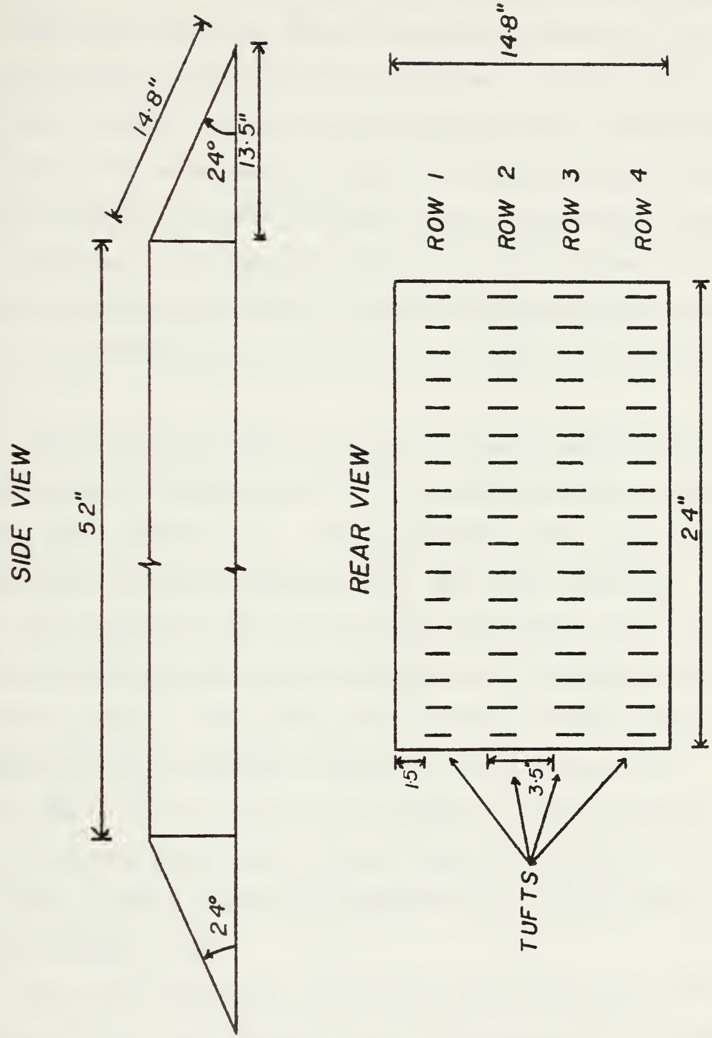
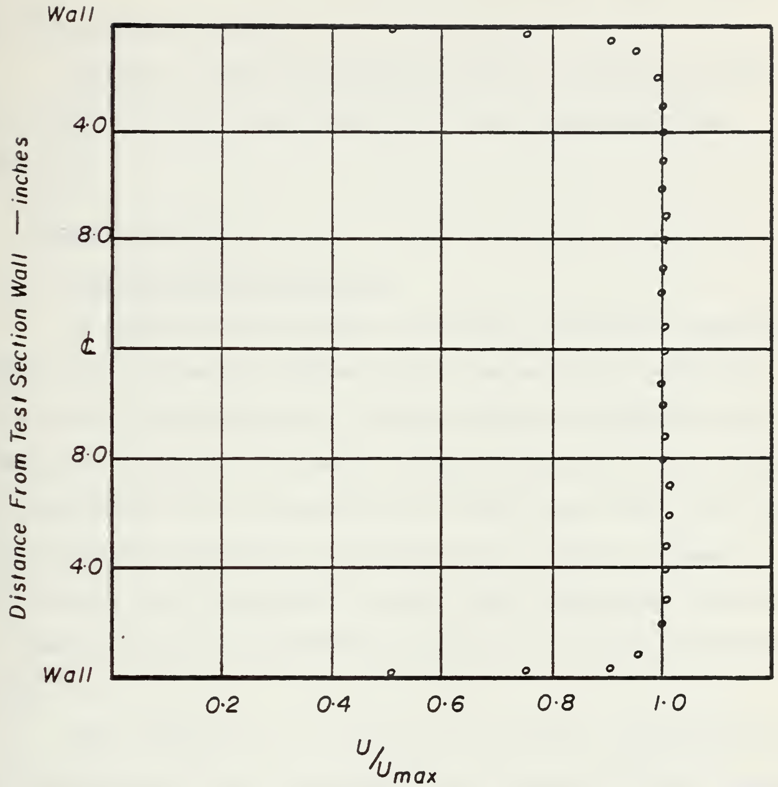


FIGURE 4

The primary model was constructed of a continuous upper surface skin of 0.100-inch thick aluminum, 62.5 inches long, which was welded to three continuous pieces of 0.25-inch thick aluminum forming three bulkheads, which were then welded to a single, flat 0.25-inch aluminum deck. The primary model was of the same general shape as the preliminary model, with an 18 degree inclined trailing edge and parabolic leading edge. Ports were cut into the six-inch high bulkheads to facilitate service of surface pressure instrumentation and to afford access to the bolts mounting the model to the tunnel floor.

Along the port side, looking forward, twenty-seven .040-inch static pressure ports were positioned four inches from the test section wall. These pressure ports ran from 22 inches aft of the leading edge in two-inch intervals until just forward of the point of the after-body ramp, where they were positioned each inch, terminating 2.5 inches from the trailing edge. The lateral positioning of these ports was determined from measured velocity profiles shown in Figure 5 [Ref. 3] in order to be outside the wall boundary layer and at the same time to leave the centerline of the model free of ports and avoid interference with the multi-channel hot-wire probe.

Two, two-inch wide, 25.5-inch long strips of 0.040-inch thick steel were imbedded into the model skin to enable a magnetically mounted multi-channel, hot-wire anemometer



TYPICAL TUNNEL TEST SECTION VELOCITY PROFILE

(U_{max} = 20 ft/sec)

FIGURE 5

probe to be easily positioned for boundary layer surveys. Figure 6 shows the relative positions of the steel tracks and the pressure ports.

Figure 7 shows the primary model in position in the test section of the wind tunnel with the instrumentation installed.

C. INSTRUMENTATION

1. Freestream Flow Sensors

A standard pitot-static tube and a hot-wire anemometer probe were located six inches above the model at mid-chord of both the preliminary and primary models to determine mean freestream velocity. Dynamic pressure was read from a Meriam micro-manometer for the preliminary model, and from a 50-tube water manometer used also to measure the surface pressure distribution for the primary model. The freestream turbulence was measured with a linearized hot-wire anemometer described in Ref. 3.

The frequency of the shutter rotation, and therefore, the frequency of flow oscillation, was measured with a digital counter which read an electrical signal developed by an optical system employing a stationary point light source and a rotating chopper wheel fixed to the top shutter valve shaft.

2. Model Surface Flow Sensors

a. Preliminary Model

The principal method of investigation for the preliminary model was the observation of tufts attached to

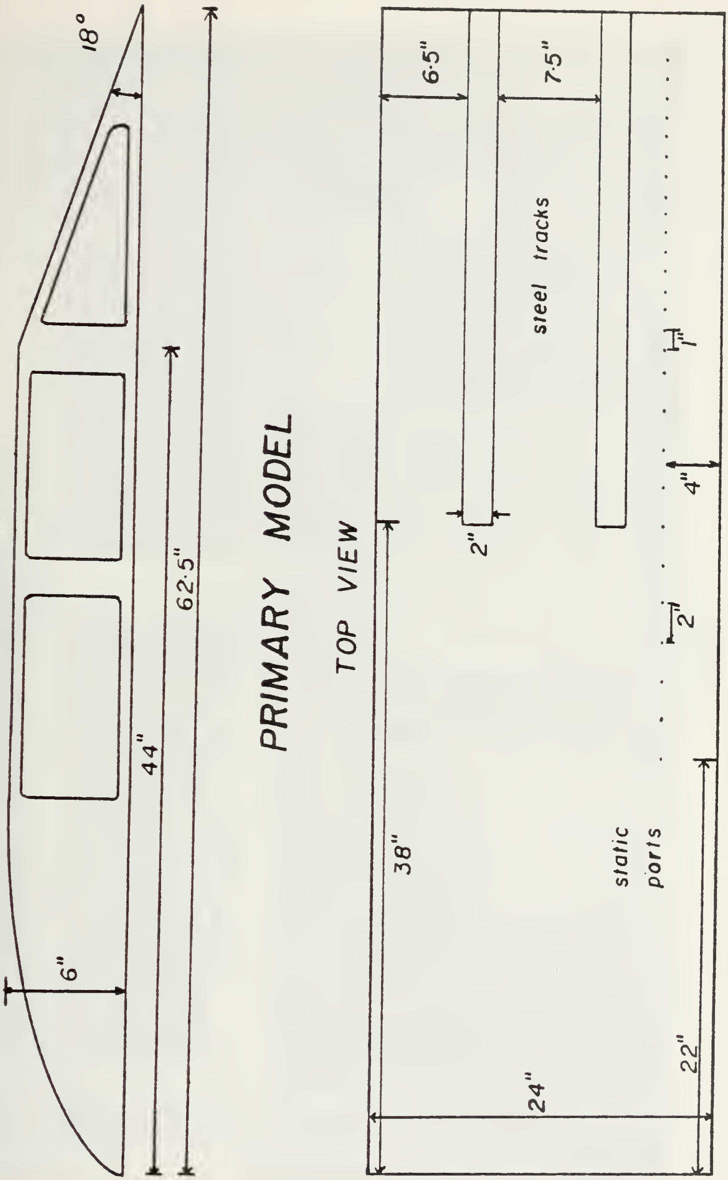

PRIMARY MODEL
SIDE VIEW
18°
6"
44"
62.5"
TOP VIEW
6.5"
7.5"
steel tracks
2"
4"
1"
2"
38"
static ports
24"
22"

FIGURE 6

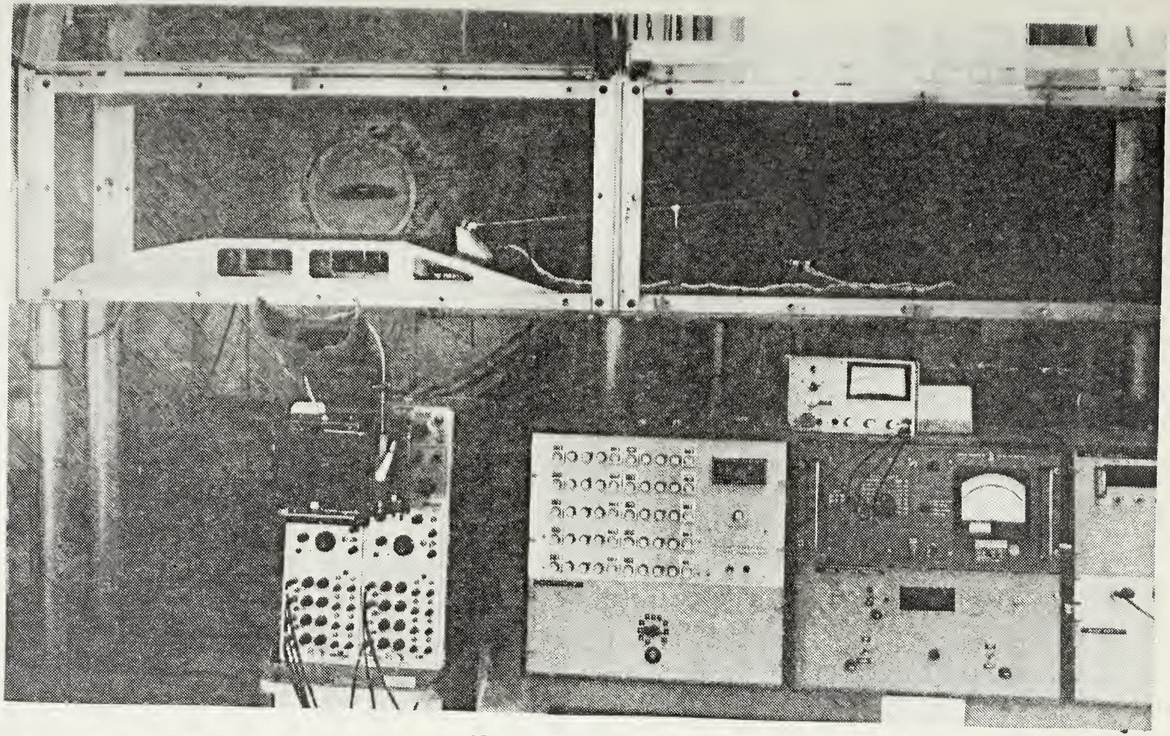


FIGURE 7

PRIMARY MODEL IN THE TEST SECTION

the divergent section. In order to facilitate these observations, a stroboscopic light was electrically triggered by a contact on the uppermost shutter shaft to permit an optical freezing of the motion of the tufts in the oscillating flow. The stroboscopic light trigger was mounted on a rotatable base assembly which allowed the tuft action to be viewed at any phase of the shutter cycle.

b. Primary Model

The surface pressure distribution over the aft two-thirds of the primary model was measured by 27 static pressure ports on the model surface. The first 11 of these ports were located on the constant area section of the model, with the remaining 16 ports located on the diverging section. Pressures at these ports were read, along with the freestream dynamic pressure, on a 50-tube water manometer calibrated in centimeters.

c. Ten-Channel Hot-Wire Probe

In order to investigate the boundary layer along the surface of the primary model, an aluminum carriage supporting ten constant temperature hot-wire anemometer probes was employed. Each hot-wire could be individually positioned from the surface to approximately three inches above the surface. The carriage stood on magnetic feet that matched the steel tracks in the model. This allowed a continuous chordwise traverse of the probe from six inches upstream of the point of divergence to approximately two inches

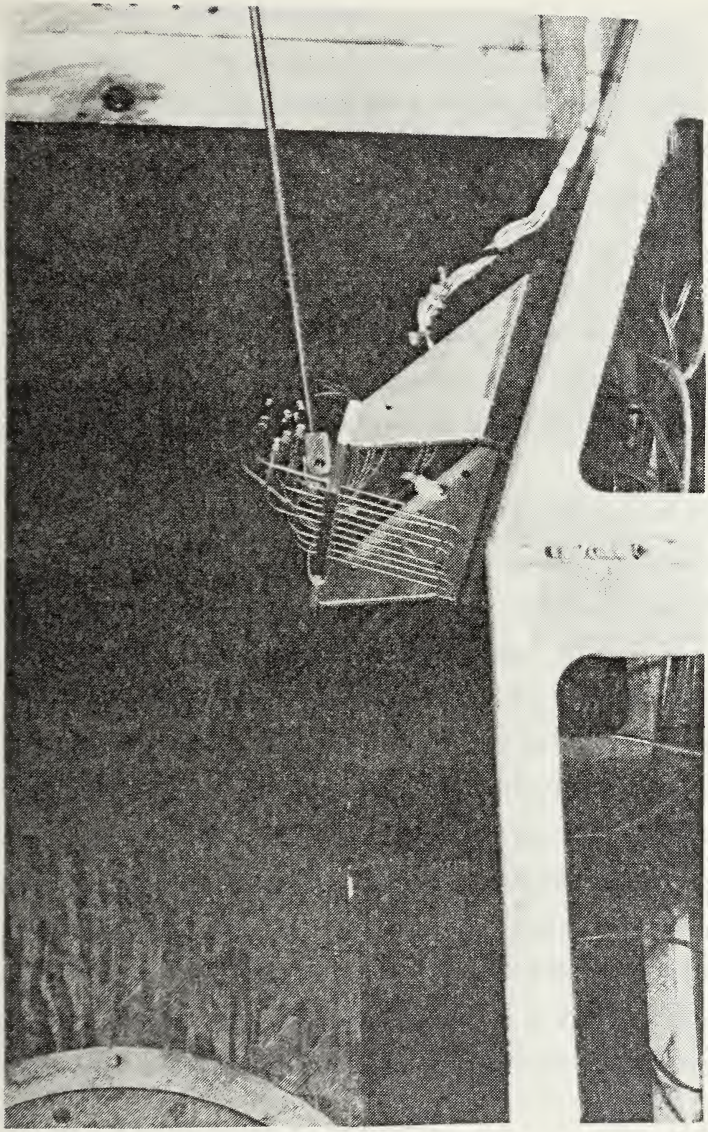


FIGURE 8

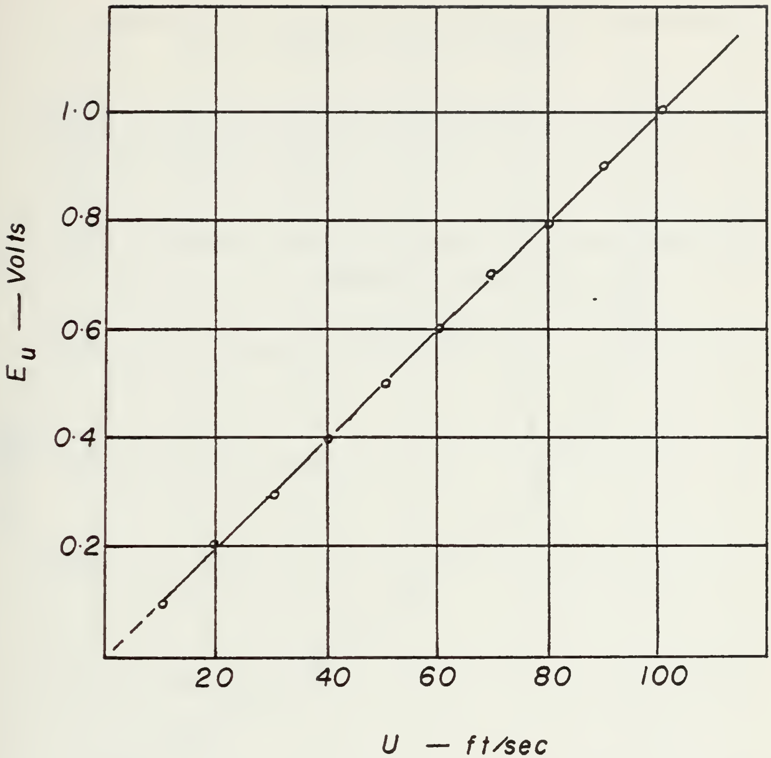
HOT-WIRE PROBE

from the trailing edge. During oscillating flow tunnel operation, the probe exhibited a tendency to "walk" along its magnetic track. In order to overcome this, a simple support rig was installed consisting of a single threaded rod, mounted to the hot-wire carriage and a streamlined stand, anchored to the tunnel floor aft of the model. Figure 8 shows the hot-wire probe in position of the model.

The ten-channel hot-wire circuits were identical to the one employed in the freestream hot-wire. Figure 9 is a typical calibration curve for non-oscillating flow, and Figure 10, a typical calibration in Blasius flow, as demonstrated by Despard [Ref. 3] and Allen [Ref. 6].

Each sensing element was a 0.00015-inch diameter tungsten filament one-eighth-inch long copper plated at its ends to facilitate mounting. The effective sensing length of each wire was approximately 0.080 inches.

Signals representing total instantaneous velocities were produced at the outputs due to the DC coupled circuitry of the anemometers. The oscillating velocity components of the total velocity are proportional to the alternating current component of the anemometer output, and were displayed on a Tektronix 555 Dual Beam oscilloscope. The oscilloscope was equipped with two, four-channel preamplifiers, permitting a maximum of eight hot-wire outputs to be viewed simultaneously. A Tektronix oscilloscope camera was used to record the multi-channel display.



TYPICAL HOT WIRE ANEMOMETER CALIBRATION CURVE
(STEADY FLOW)

FIGURE 9

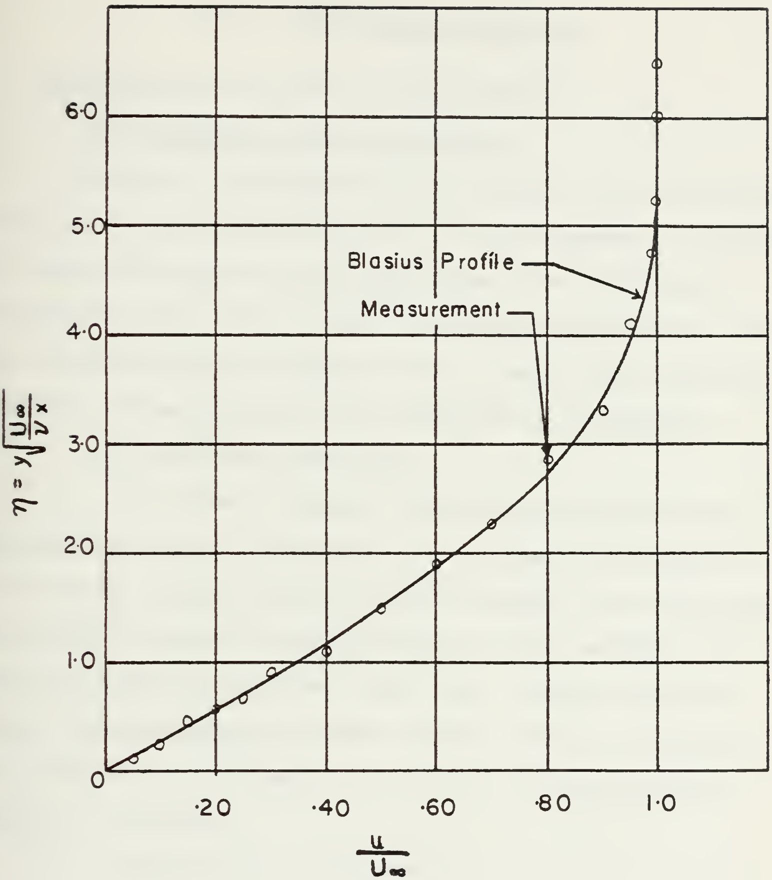


FIGURE 10

TYPICAL HOT WIRE ANEMOMETER CALIBRATION
VELOCITY PROFILE IN BLASIUS FLOW

III. EXPERIMENTAL PROCEDURE

A. DETERMINATION OF PRIMARY MODEL GEOMETRY

1. Freestream Flow Characteristics

Prior to investigating the boundary layer characteristics of the preliminary model, it was necessary to determine the operating ranges of the freestream flow variables in oscillating flow with the model installed in the test section. The flow variables of interest were: mean tunnel velocity, frequency of oscillation, and amplitude of oscillation.

a. Mean Tunnel Velocity

In order to insure a turbulent boundary layer over the trailing edge of the model, mean tunnel velocities of 111 feet per second, 132.37 feet per second, and 148.16 feet per second, were set and maintained via the variable inlet vanes and measured with the pitot tube. These velocities yielded Reynolds numbers, under average ambient conditions of 3.8×10^6, 4.5×10^6, and 5.1×10^6 for a characteristic length of 70 inches.

b. Frequency of Oscillation

Shutter rotation frequencies, and therefore, flow oscillation frequencies, of from 1 to 100 Hertz were investigated in the initial testing. The frequencies were measured by the previously described electro-optical system and were read directly from the digital frequency counter. Shutter frequency

was varied from one to six Hertz in one Hertz increments, and from 20 to 100 Hertz in two Hertz increments for a single mean velocity. The frequency range of from 6 to 20 Hertz was not investigated due to shutter drive gearing difficulties. Oscillation frequency was then retarded from 100 Hertz to one Hertz by reversing the above procedure while maintaining a constant mean tunnel velocity.

c. Amplitude of Oscillation

The amplitude of oscillation was measured with the single-channel freestream hot-wire anemometer and the AC component was read with a Ballantine true RMS voltmeter. These readings were of change in streamwise velocity normalized with freestream mean velocity (N_A). Amplitude readings were taken at each frequency while traversing the frequency range in the upward direction, then confirmed while descending the frequency range.

Several experimental runs were made at each of the mean velocities with two full data collection runs made for each of the lower mean velocities, and one for the highest velocity. Due to instrument fluctuations experienced at frequencies less than four Hertz, the oscillation amplitude values for the lowest frequencies were considered at best approximate and were not reported.

2. Boundary Layer Separation on Preliminary Model

The paramount purpose of the preliminary investigation was to determine the combination of leading and trailing edge

sections that would give rise to turbulent boundary layer separation on the trailing edge section. The use of tufts on the trailing edge sections was believed to be the most reliable and expedient method to study the desired phenomenon, given the lack of instrumentation incorporated into the preliminary model.

It became clear early in the testing that the leading edge section had no real effect upon the desired conditions, therefore, the 24-degree leading edge section was fixed in position for the duration of the experiment.

The trailing edge sections were affixed with tufts, as shown in Figure 4, and the model was run through the range of freestream conditions. The stroboscopic light was connected to the shutter shaft and cam, and was positioned so as to effectively light the tufts. The reaction of the tufts to the flow was visually studied to determine the effects of flow oscillation on boundary layer separation. Numerous experimental runs were made with the several trailing edge sections under the various freestream conditions and with stroboscopic and normal lighting.

3. Design of Primary Model

From the results of the preliminary investigation, it was concluded that the primary model should be of similar dimensions to those of the preliminary model with a trailing edge incline of 18 degrees to best produce a turbulent boundary layer that would separate at the desired location

under test conditions. Due to structural difficulties experienced with the wooden preliminary models, it was also concluded that the primary model should be designed with increased strength. The primary model constructed under the above criteria was somewhat smaller in the chordwise dimension than the preliminary model. The shorter chordwise dimension positioned the divergent section of the model 45 inches from the leading edge. This shortening of the chord for the primary model allowed a single test section panel bolting and unbolting requirement for maintenance ease, but still produced a sufficiently high Reynolds number at one-half of the lowest preliminary test mean velocity. Jacobs [Ref. 7] determined that a turbulent boundary layer would occur at a Reynolds number of approximately 1.0×10^6 for a flat plate, in this identical wind tunnel under similar test conditions. The primary model would experience a Reynolds number of 1.2×10^6 at the point of divergence with a mean velocity of 55 feet per second.

B. PRESSURE DISTRIBUTION ON PRIMARY MODEL

The pressure distribution over the primary model from a position 22 inches aft of the leading edge to the trailing edge was determined by use of static pressure ports and a manometer board. Several runs were made with both the 67 per cent and 98 per cent occlusion shutter blades installed. The frequency values used for data collection were 1, 2, 4, 6, and 25 Herts, for both sets of shutter blades, 30 to 100 Hertz,

and 30 to 70 Hertz, in ten Hertz increments, for the 67 per cent and 98 per cent blades respectively. Considering that the nondimensional coefficient of pressure (C_p) was to be the ultimate output of these runs, mean tunnel velocity was not necessarily kept constant throughout the frequency range.

A maximum freestream oscillation amplitude at six Hertz was noted during this phase of the experiment as being 108 per cent, while using the large shutter blades.

C. BOUNDARY LAYER CHARACTERISTICS

The boundary layer over the model was monitored to ensure turbulent flow with the aide of the ten-channel hot-wire probe and the eight-trace oscilloscope. Evidence of turbulent flow was taken to be the characteristic oscilloscope trace for turbulence as discussed by Bradshaw [Ref. 8].

Prior to each experimental run, calibration of the hot-wire anemometers was carried out in situ. The positioning of the boundary layer probe's wires with respect to height above the model was then set. The final setting of the individual anemometers was accomplished after the calibration in consideration of the possibility that one or more of the wires may have failed the calibration procedure. The wire heights could then be adjusted so as to provide adequate coverage of the boundary layer without the need to remove the entire probe for repair. For the purposes of this initial investigation, a meaningful run could be made with the free-stream anemometer and five of the boundary layer anemometers

being in calibration. The heights above the model surface, for this worst-case hot-wire availability, were a wire each at 0.05, 0.10, 0.20, 0.30, and 0.40 inches.

The wind tunnel was set to operate with an oscillation frequency of 20 Hertz, oscillation amplitude of 18 per cent, mean velocity of 15 feet per second, and the large shutter blades installed. Photographs of the multi-trace oscilloscope were taken with the hot-wire carriage set at various chordwise positions. After completing this overall chorwise survey, the carriage was positioned five inches downstream of the point of model divergence. This mean freestream velocity was then varied from 22 to 88 feet per second, and the oscillation frequency varied from 20 to 70 Hertz, to complete this initial turbulent boundary layer survey.

IV. RESULTS

A. PRELIMINARY MODEL

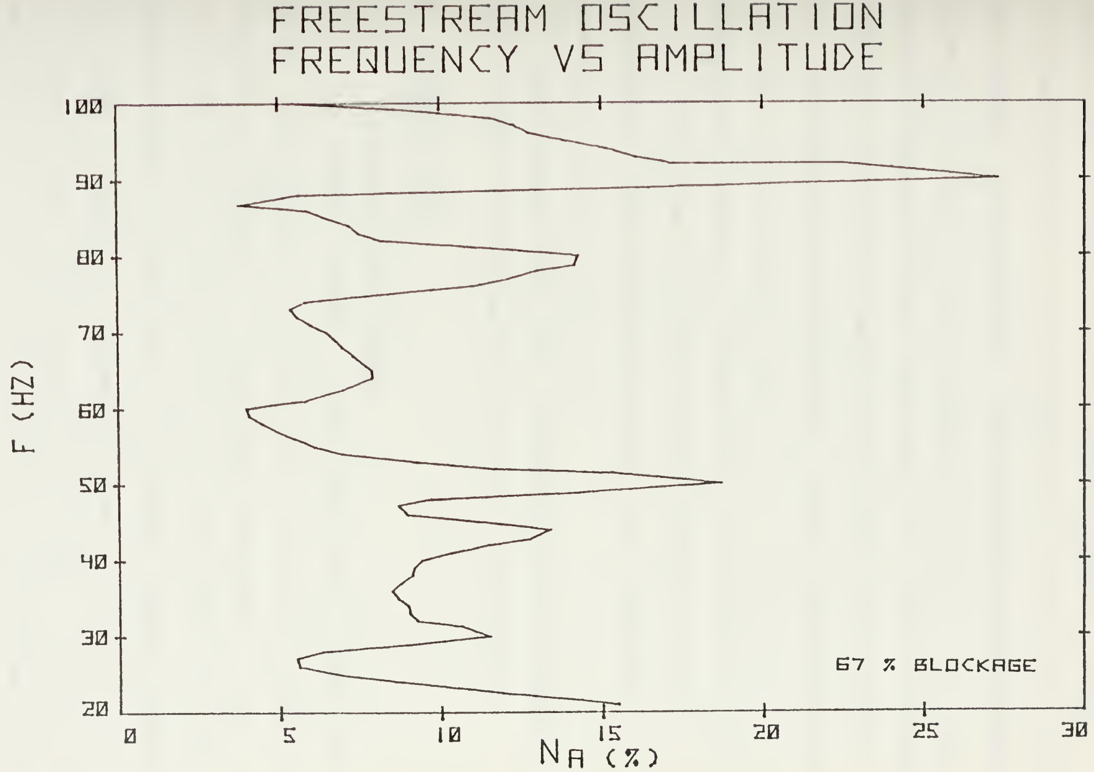
1. Oscillation Amplitude Versus Frequency

The data collected from the freestream amplitude investigation for the selected mean velocities indicates that the mean velocity had little or no effect upon the nondimensional amplitude factor, N_A. A study of the data shows that for a specific oscillation frequency (f), the values obtained for N_A were usually within one per cent of each other for any of the mean velocities tested. Due to this similarlity, the values of amplitudes, for a given frequency, were arithmetically averaged in order to be plotted against oscillation frequency. Figure 11 is the graph of oscillation amplitude versus oscillation frequency for a tunnel occlusion of 67 per cent.

Figure 11 reveals the bulk of the values of N_A to lie between 5 and 15 per cent. Values larger than 15 per cent are seen to have occurred at 21 - 22 Hz, and 90 - 94 Hz. Other, less prominent, peaks occurred in the vicinity of 30 Hz, 40 Hz, and 80 Hz.

2. Boundary Layer Activity

The tufting of the preliminary model, as shown in Figure 4, clearly evidenced a turbulent boundary layer in existence over the area of interest in the case of the 18 and



FREESTREAM OSCILLATION
FREQUENCY VS AMPLITUDE
F (HZ)
100
90
80
70
60
50
40
30
20
0
5
10
15
20
25
30
NA (%)
67 % BLOCKAGE

FIGURE 11

24 degree diverging model sections. Close study of the 24 degree section showed that the boundary layer remained attached to the Row 1 area (Figure 4) as oscillation began from steady flow conditions. The boundary layer remained attached in this area until approximately 28 Hz when the entire diverging section became stalled. The fully stalled condition continued through approximately 70 Hz, when the Row 1 area again showed turbulent boundary layer attachment. The entire section again became fully stalled at the 80 Hz reading and remained so through the test limit of 100 Hz.

The 18 degree diverging section displayed similar frequency response but the turbulent boundary layer attachment point had moved into the Row 2 and 3 area.

These results were quite repeatable and consistent throughout the range of mean velocities (111 - 148 ft/sec).

B. PRIMARY MODEL

1. Pressure Distribution

A surface pressure survey was conducted with both the 67 per cent and the 98 per cent flow blockage shutter blades installed. The range of oscillation frequency (f) was 1 Hz to 100 Hz for the former and 1 Hz to 70 Hz for the latter shutter blade configuration. To preclude physical damage, the larger occlusion tests were limited to the 70 Hz level due to violent tunnel behavior above this value. In fact, data was collected at 80 Hz with the 98 per cent blades installed,

but, due to equipment vibration, that data point was not repeated and therefore considered unreliable.

Figures 12, 13, and 14 depict the pressure coefficient (C_p) measured at each of the 27 pressure ports from 31.2 to 96 per cent chord for the case of 67 per cent flow blockage. The peak of these curves (lowest value of C_p) occurs uniformly at port number 11 which was located just upstream of the point of model divergence at 67 per cent chord. As may be seen, the C_p curves remain generally smooth throughout the frequency range with all values of C_p remaining more positive than the steady state (f = 0 Hz) values.

The curves for frequencies of one Hz, two Hz, and four Hz were identical to the curve for six Hz and were not presented. As may be seen, the curve for six Hz is nearly identical to the steady state value.

The values for 25 Hz, 40 Hz, and 80 Hz are also nearly identical to each other. The curves of 30 Hz, 50 Hz, and 90 Hz duplicate each other and are somewhat less negative than the 25 Hz series. The values for 100 Hz stand alone at the most positive edge of the family.

The differences between the curves becomes generally less pronounced downstream of the point of model divergence. The values for 6 Hz, 25 Hz, and 30 Hz all merge at the 90 per cent chord point. The 50 Hz and 60 Hz curves become nearly coincident aft of 70 per cent chord. A similar situation occurs for the 90 and 100 Hz C_p values.

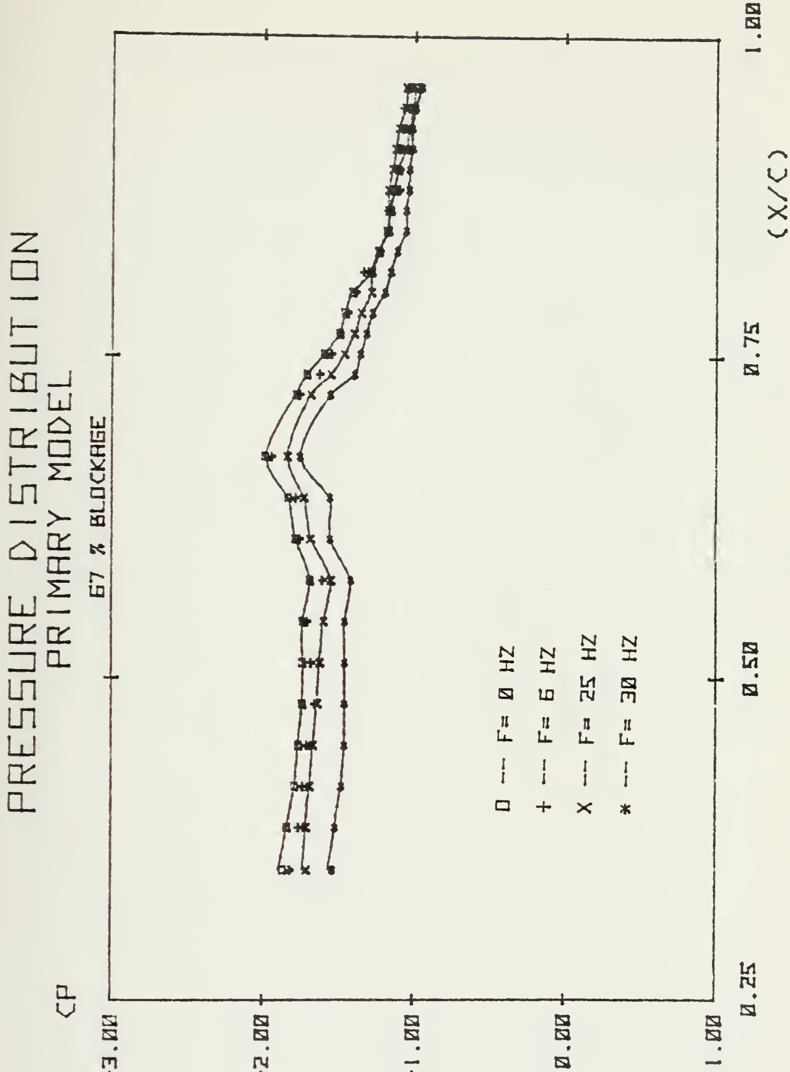

PRESSURE DISTRIBUTION
PRIMARY MODEL
67 % BLOCKAGE
CP
-3.00
-2.00
-1.00
0.00
1.00
0.25
0.50
0.75
1.00
(X/C)
□ --- F= 0 HZ
+ --- F= 6 HZ
X --- F= 25 HZ
* --- F= 30 HZ

FIGURE 12

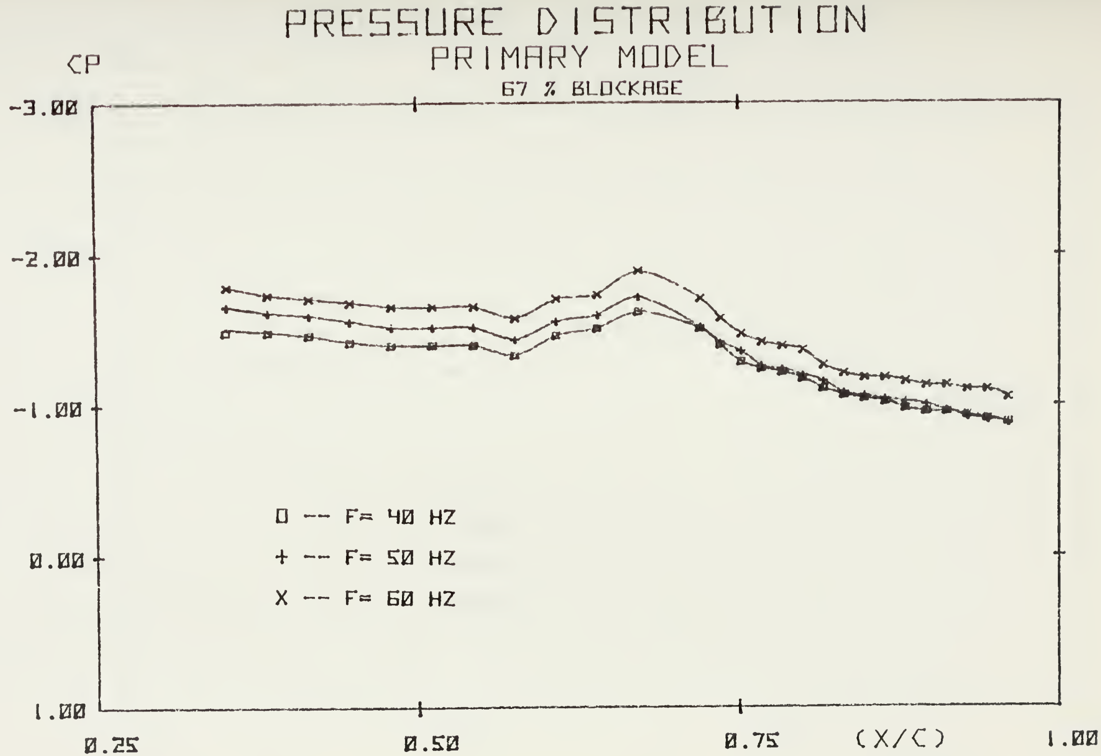

PRESSURE DISTRIBUTION
PRIMARY MODEL
67 % BLOCKAGE
CP
-3.00
-2.00
-1.00
0.00
1.00
0.25
0.50
0.75
(X/C)
1.00
□ -- F= 40 HZ
+ -- F= 50 HZ
X -- F= 60 HZ

FIGURE 13

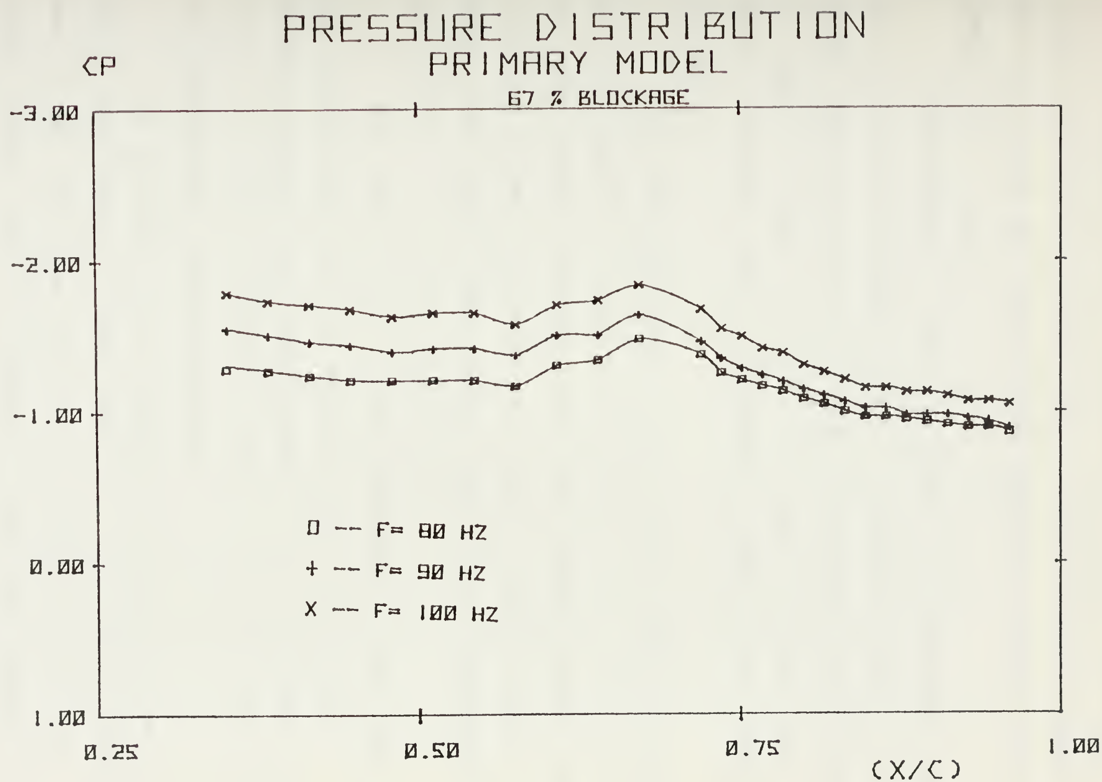

PRESSURE DISTRIBUTION
PRIMARY MODEL
67 % BLOCKAGE
CP
-3.00
-2.00
-1.00
0.00
1.00
0.25
0.50
0.75
1.00
(X/C)
O -- F= 80 HZ
+ -- F= 90 HZ
X -- F= 100 HZ

FIGURE 14

Figures 15 and 16 present the pressure coefficient versus chord for the 98 per cent occlusion shutter blades. Here the one Hz and two Hz values track very closely with the steady flow C_p curve.

This family of curves behaves much differently than the 67 per cent blockage curves. In general, there is a much larger range of values of C_p over the frequency range than the smaller blockage, and the curves tend to be much more erratic in their behavior. Except as noted, no two curves are alike.

The curve depicting an f of four Hz begins at values much less negative than the steady state case, joining it at the point of model divergence and then dropping sharply off until the 80 per cent chord point where it again rises to become more negative than steady state only to immediately fall off to a C_p value of nearly zero.

The six Hz curve is nearly identical to the shape of the four Hz curve with the exception that the C_p value remains constant until approximately 70 per cent chord. The six Hz curve also fluctuates at 80 per cent chord then drops off sharply to C_p values near +0.5.

As the oscillation frequency is increased, the curves become less erratic in their behavior. The 25 Hz curve shows some of the tendencies of the 4 and 6 Hz curves, but at a reduced level. The 60 Hz curve is nearly flat, while the 70 Hz curve is indeed a straight line until approximately 90 per cent chord, where it slowly increases.

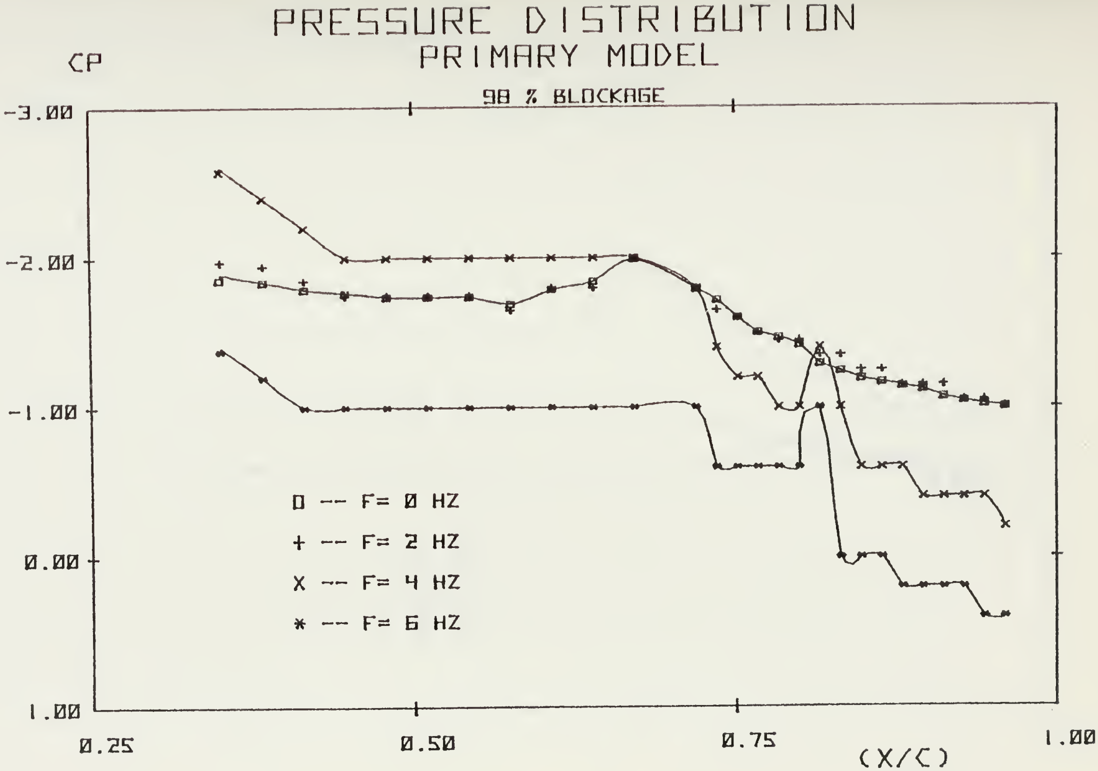

PRESSURE DISTRIBUTION
PRIMARY MODEL
98 % BLOCKAGE
CP
-3.00
-2.00
-1.00
0.00
1.00
0.25
0.50
0.75
1.00
(X/C)
□ -- F= 0 HZ
+ -- F= 2 HZ
X -- F= 4 HZ
* -- F= 6 HZ

FIGURE 15.

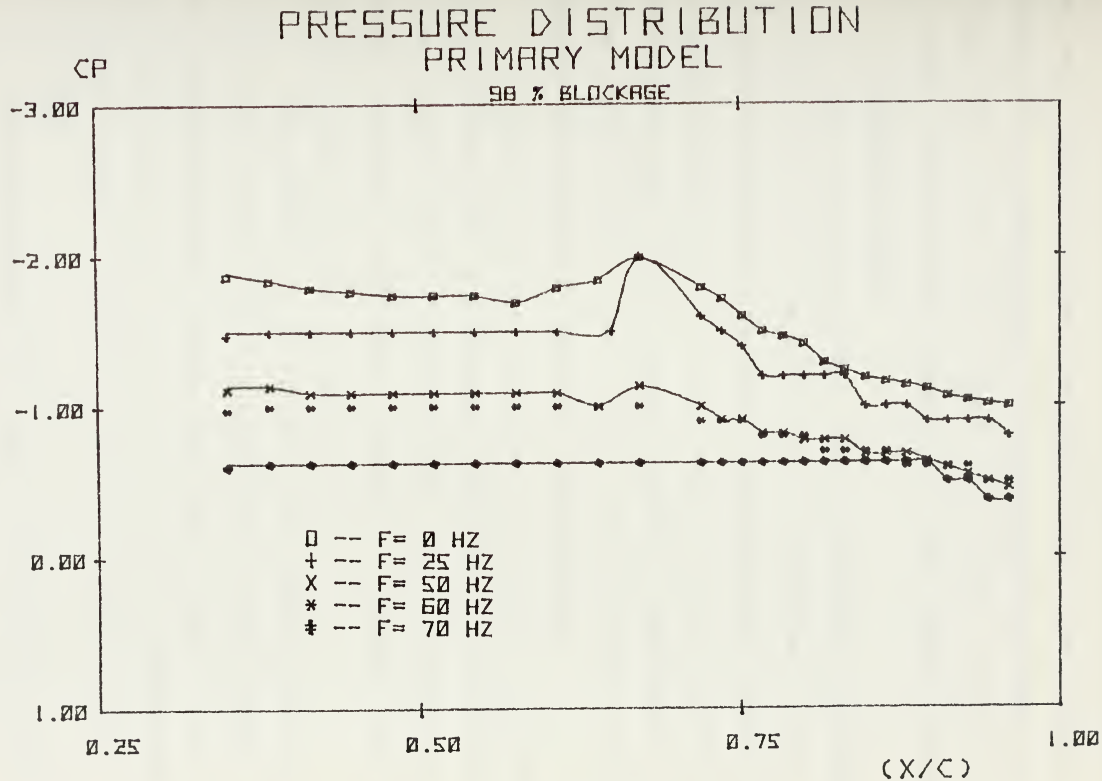

PRESSURE DISTRIBUTION
PRIMARY MODEL
98 % BLOCKAGE
CP
-3.00
-2.00
-1.00
0.00
1.00
0.25
0.50
0.75
1.00
(X/C)
□ -- F= 0 HZ
+ -- F= 25 HZ
X -- F= 50 HZ
* -- F= 60 HZ
‡ -- F= 70 HZ

FIGURE 16

It should be noted that the large water manometer board was well suited for this investigation due to the natural damping of its measurements. It was relatively simple to obtain the pressure data without the averaging necessary with a faster response system, especially at the higher frequencies.

2. Boundary Layer

The turbulent boundary layer investigation performed on the primary model was designed as a preliminary check on apparatus suitability, operating procedures, and identification of potential problems for future study of the flow phenomenon. With these goals in mind, several series of experimental runs were performed with the ten-channel hot-wire probe, and all associated equipment in position and operating.

It was found that the setup and electronic calibration of the probe could be performed efficiently and accurately after a short initial learning period. This included the manual setting of individual anemometer heights and identification of any broken or questionable hot-wires.

The security of the probe on its magnetic feet and steel traverse was improved considerably by the addition of the supporting rod and stand. The probe was easy to move to any position and was secure in that position throughout the frequency range of from 20 Hz to 70 Hz at several mean velocities.

The satisfactory performance of the primary model and its measuring equipment was demonstrated during a

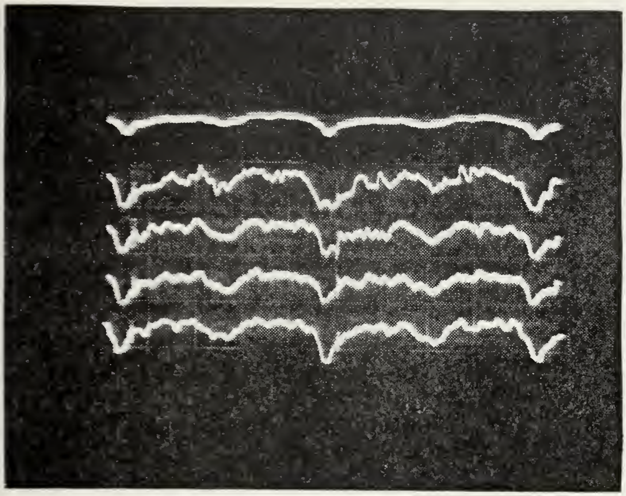
simulated data collection run. Figures 17 - 20 are typical of the oscillographs taken from the multi-trace oscilloscope during this final experiment. The uppermost trace depicts the freestream flow read from the test section single hot-wire anemometer. The second through fifth trace shows the boundary layer flow at 0.05 inches, 0.10 inches, 0.20 inches, and 0.30 inches above the model surface. The sixth trace, if present, depicts the boundary layer at 0.40 inches above the model. The tunnel was run with the 98 per cent occlusion shutter blades installed.

The freestream conditions for Figures 17 and 18 were mean velocity set at 42 feet per second, oscillation frequency set at 20 Hz, yielding an oscillation amplitude of 18 per cent. The variable in the four oscillographs is the location of the probe on the model. The range of locations shown are from 2 inches upstream of the model divergence point, ($^x/c = .67$), to 14 inches downstream, ($^x/c = .93$).

The oscillographs in Figure 19 and the upper one in Figure 20 are for a fixed probe location of five inches downstream of the model divergence point, ($^x/c = .78$). Mean tunnel velocity was increased to 51.4 feet per second and frequency was made the variable. Note the increase in oscillation amplitude for the 20 Hz case. It was shown for the 67 per cent occlusion blades that the mean freestream velocity had no effect upon the value of N_A. The lower oscillograph in Figure 20 is at the same conditions as the 20 Hz

oscillograph of Figure 19 with the exception that the mean velocity was increased to 103 feet per second. The oscillation amplitude, however, remained the same as the 51.4 feet per second case.

It is clear that the boundary layer was entirely turbulent throughout this test.



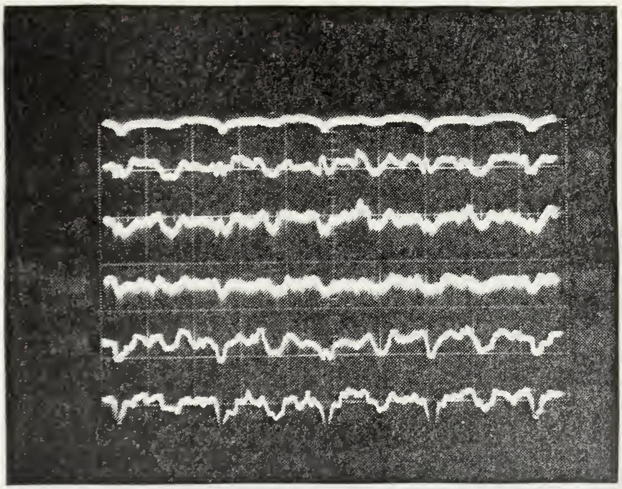
f = 20 Hz

$^x/c$ = .67

$\bar{U}$ = 42 ft/s

N_A = 18%

TYPICAL OSCILLOGRAPHS



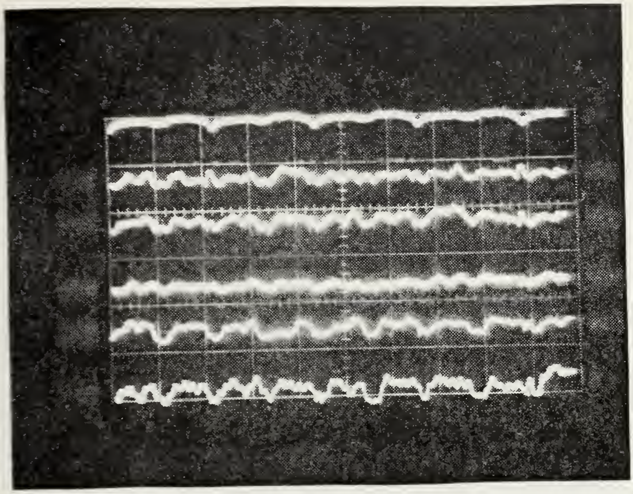
f = 20 Hz

$^x/c$ = .78

$\bar{U}$ = 42 ft/s

N_A = 18%

FIGURE 17



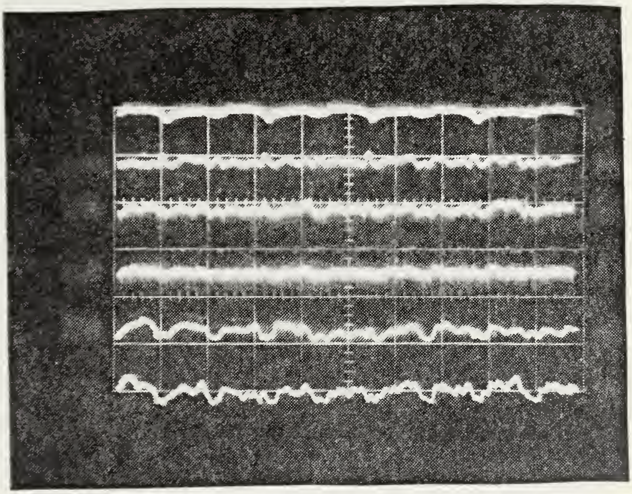
f = 20 Hz

x/c = .84

$\bar{U}$ = 42 ft/s

N_A = 18%

TYPICAL OSCILLOGRAPHS



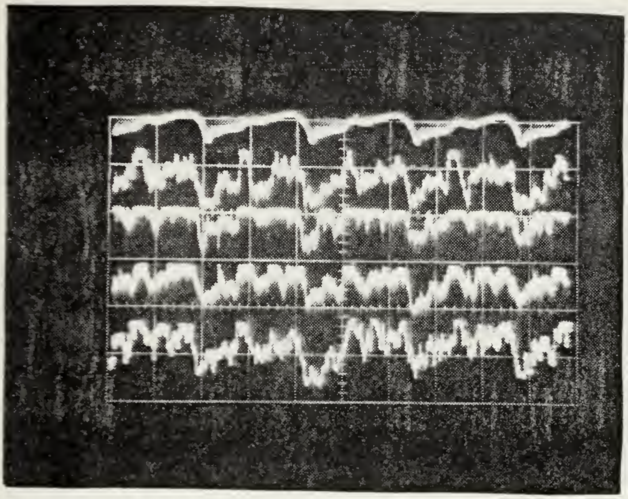
f = 20 Hz

x/c = .93

$\bar{U}$ = 42 ft/s

N_A = 18%

FIGURE 18



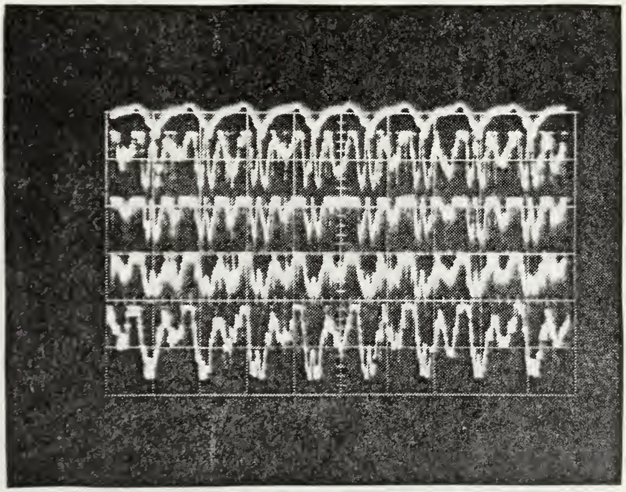
f = 20 Hz

$^x/_c$ = .78

$\overline{U}$ = 51.4 ft/s

N_A = 35%

TYPICAL OSCILLOGRAPHS



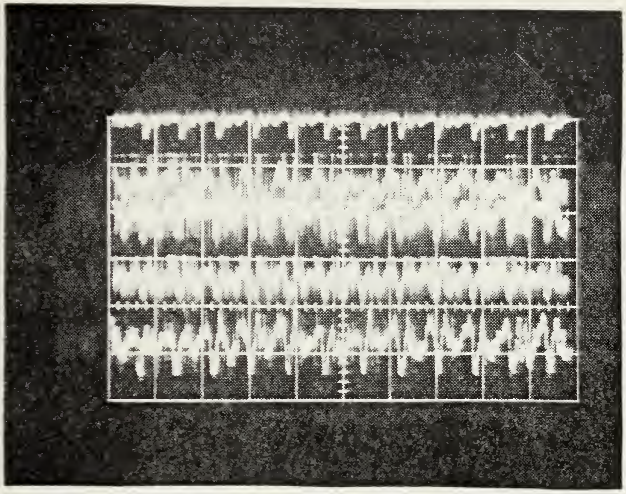
f = 40 Hz

$^x/_c$ = .78

$\overline{U}$ = 51.4 ft/s

N_A = 39%

FIGURE 19.



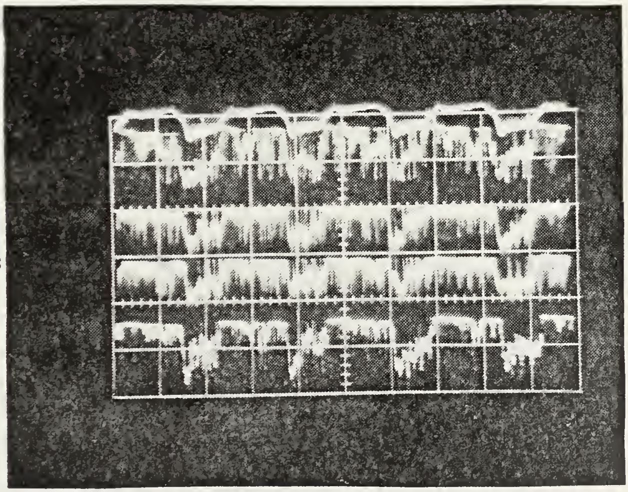
$f = 60$ Hz

$x/c = .78$

$\bar{U} = 51.4$ ft/s

$N_A = 29\%$

TYPICAL OSCILLOGRAPHS



$f = 20$ Hz

$x/c = .77$

$\bar{U} = 103$ ft/s

$N_A = 35\%$

FIGURE 20

V. CONCLUSIONS

From the results described above, the following conclusions may be drawn:

Oscillation amplitude is clearly a function of oscillation frequency in this tunnel and may increase dramatically with little change in frequency. The amplitude change of from less than 5 per cent at 88 Hz to over 27 per cent at 90 Hz is certain evidence of this fact.

The effect of mean freestream velocity upon oscillation amplitude, when coupled with large flow occlusions, is not clear. The mean freestream velocity showed to have no noticeable effect upon amplitude in the 67 per cent flow occlusion study; however, the 98 per cent occlusion tests showed mixed results. The amplitude doubled with a 22 per cent increase in tunnel velocity at one point, but then remained constant with a 100 per cent increase in mean velocity.

Turbulent boundary layer separation over a two-dimensional body may be affected by flow oscillation frequency. The results of the tuft experiment support this conclusion.

The primary model design and construction is satisfactory for the investigation of the effect of freestream oscillation on turbulent boundary layer separation.

The ten-channel hot-wire boundary layer probe performed well, but due to the large aerodynamic forces capable of being produced by the tunnel, should be adequately braced in the streamwise direction.

APPENDIX EXPERIMENTAL DATA

TABLE I

MEASURED DIMENSIONLESS OSCILLATION AMPLITUDE AS A FUNCTION OF FREQUENCY

f (HZ)	N_A (%)	f (HZ)	N_A (%)
4	18.0	60	4.0
5	15.0	62	5.8
6	11.5	64	7.9
21	15.5	66	7.6
24	8.8	68	7.0
26	5.6	70	6.5
28	6.3	72	5.6
30	11.5	74	5.8
32	9.3	76	11.0
34	9.0	78	13.0
36	8.5	80	14.3
38	9.1	82	8.2
40	9.4	84	7.2
42	11.5	86	5.9
44	13.4	88	5.6
46	9.0	90	27.3
48	9.7	92	17.3
50	18.7	94	15.2
52	11.7	96	12.8
54	7.0	98	11.6
56	5.5	100	5.5
58	4.5		

NOTE:
1. Data reduced from raw data by arithmetic averaging.
2. f is Oscillation Frequency in Hertz.
3. N_A is nondimensional Oscillation Amplitude ($\Delta u/\overline{U}$).

TABLE II

EXPERIMENTAL OSCILLATION
FREQUENCIES AND
AMPLITUDES DATA

$q = 7$ cm H_2O $p = 29.98$ in Hg $T = 70^oF$

f (HZ)	N_A (%)	f (HZ)	N_A (%)
4	17.5	60	5.0
5	15.5	62	6.5
6	11.0	64	8.5
22	15.0	66	8.0
24	8.0	68	7.5
26	5.0	70	7.0
28	5.0	72	6.0
30	11.0	74	5.0
32	9.0	76	13.0
34	8.5	78	15.0
36	8.5	80	16.0
38	9.5	82	8.5
40	10.0	84	8.0
42	11.0	86	7.0
46	8.5	88	6.5
48	9.5	90	25.0
50	18.0	92	17.0
52	13.0	94	15.0
54	6.5	96	13.5
56	5.5	98	12.0
58	4.5	100	5.0

TABLE II (continued)

EXPERIMENTAL OSCILLATION
FREQUENCIES AND
AMPLITUDES DATA

$q = 7$ cm H_2O $p = 29.98$ in Hg $T = 70^{\circ}F$

f (HZ)	N_A (%)	f (HZ)	N_A (%)
4	18.0	60	5.0
5	15.0	62	6.5
6	11.5	64	9.0
21	16.5	66	8.5
24	8.5	68	7.5
26	5.0	70	6.5
28	5.5	72	6.0
30	11.5	74	5.5
32	9.0	76	12.0
34	9.0	78	14.5
36	8.5	80	15.5
38	9.0	82	8.0
40	9.5	84	7.0
43	12.5	86	6.0
46	8.5	88	5.5
48	9.5	90	30.0
50	19.0	92	20.0
54	6.0	94	17.0
56	5.0	98	13.5
58	4.5	100	7.0

TABLE II (continued)

EXPERIMENTAL OSCILLATION
FREQUENCIES AND
AMPLITUDES DATA

$q = 10$ cm H_2O $p = 30.00$ in Hg $T = 68^{o}F$

f (HZ)	N_A (%)	f (HZ)	N_A (%)
21	14.0	62	4.5
23	13.5	64	6.5
24	10.0	66	7.0
26	7.0	68	6.8
28	8.0	70	6.5
30	11.5	72	5.2
32	10.0	74	6.0
34	9.5	76	9.8
36	9.0	78	10.5
38	9.5	80	13.0
40	9.5	82	8.5
44	14.0	84	7.0
46	9.5	86	5.5
48	10.0	88	5.0
50	18.0	90	27.0
52	11.0	92	19.0
54	8.0	94	15.0
56	6.0	96	12.0
58	4.8	98	10.0
60	3.5	100	5.0

TABLE II (continued)

EXPERIMENTAL OSCILLATION
FREQUENCIES AND
AMPLITUDES DATA

q = 10 cm H_2O p = 30.00 in Hg T = 68^oF

f (HZ)	N_A (%)	f (HZ)	N_A (%)
22	14.5	64	7.0
24	9.5	66	7.5
26	6.5	68	7.0
28	7.0	70	6.5
30	12.0	72	6.0
32	9.5	74	6.5
34	9.5	76	10.0
36	8.5	78	11.5
38	8.5	80	14.0
40	9.0	82	8.5
44	13.5	84	7.5
46	10.0	86	6.0
48	10.0	88	5.5
50	18.5	90	28.5
52	11.0	92	19.5
54	8.5	94	16.0
56	6.0	96	13.0
58	5.0	98	11.0
60	3.5	100	6.0
62	5.5		

TABLE II (continued)

EXPERIMENTAL OSCILLATION FREQUENCIES AND AMPLITUDES DATA

$q = 12.5$ cm H_2O $p = 29.99$ in Hg $T = 69^oF$

f (HZ)	N_A (%)	f (HZ)	N_A (%)
4	19.0	58	3.5
5	14.5	60	3.0
6	12.0	64	8.5
21	16.0	66	7.0
24	8.0	68	6.5
26	4.5	70	6.0
28	6.0	72	5.0
30	11.5	74	6.0
32	9.0	76	10.5
34	8.5	80	13.0
36	8.0	82	7.5
40	9.0	84	6.5
44	13.0	86	5.0
46	8.0	88	5.5
48	9.5	90	26.0
50	20.0	92	15.0
54	6.5	94	13.0
56	5.0	100	4.5

TABLE III

MEASURED SURFACE PRESSURES

```
 0    HZ
 68   TEMP (F)
ATMOS PRESS (PSF) 2115.7848
TUNNEL PRESS (PSF) 2074.8728
TUNNEL Q (PSF) 40.912
TUNNEL VELOC (FPS) 187.1977405

PORT #  1
X/C=  0.352
PORT PRESS=  1997.54912
CP= -1.89

PORT #  2
X/C=  0.384
PORT PRESS=  1999.59472
CP= -1.84

PORT #  3
X/C=  0.416
PORT PRESS=  2001.64032
CP= -1.79

PORT #  4
X/C=  0.448
PORT PRESS=  2002.66312
CP= -1.765

PORT #  5
X/C=  0.48
PORT PRESS=  2003.68592
CP= -1.74

PORT #  6
X/C=  0.512
PORT PRESS=  2003.68592
CP= -1.74

PORT #  7
X/C=  0.544
PORT PRESS=  2003.68592
CP= -1.74

PORT #  8
X/C=  0.576
PORT PRESS=  2005.73152
CP= -1.69

PORT #  9
X/C=  0.608
PORT PRESS=  2001.64032
CP= -1.79

PORT #  10
X/C=  0.64
PORT PRESS=  1999.59472
CP= -1.84

PORT #  11
X/C=  0.672
PORT PRESS=  1993.45792
CP= -1.99

PORT #  12
X/C=  0.72
PORT PRESS=  2001.64032
CP= -1.79

PORT #  13
X/C=  0.736
PORT PRESS=  2004.70872
CP= -1.715

PORT #  14
X/C=  0.752
PORT PRESS=  2009.4136
CP= -1.6

PORT #  15
X/C=  0.768
PORT PRESS=  2068.736
CP= -0.15

PORT #  16
X/C=  0.784
PORT PRESS=  2014.93672
CP= -1.465

PORT #  17
X/C=  0.8
PORT PRESS=  2016.98232
CP= -1.415

PORT #  18
X/C=  0.816
PORT PRESS=  2022.09632
CP= -1.29

PORT #  19
X/C=  0.632
PORT PRESS=  2024.14192
CP= -1.24

PORT #  20
X/C=  0.848
PORT PRESS=  2026.18752
CP= -1.19

PORT #  21
X/C=  0.864
PORT PRESS=  2027.21032
CP= -1.165

PORT #  22
X/C=  0.88
PORT PRESS=  2028.23312
CP= -1.14

PORT #  23
X/C=  0.896
PORT PRESS=  2029.25592
CP= -1.115

PORT #  24
X/C=  0.912
PORT PRESS=  2031.30152
CP= -1.065

PORT #  25
X/C=  0.928
PORT PRESS=  2032.32432
CP= -1.04

PORT #  26
X/C=  0.944
PORT PRESS=  2033.34712
CP= -1.015

PORT #  27
X/C=  0.96
PORT PRESS=  2033.9608
CP= -1
```

TABLE III (continued)

MEASURED SURFACE PRESSURES

```
 1    HZ
 68   TEMP (F)
ATMOS PRESS (PSF) 2115.7648
TUNNEL PRESS (PSF) 2105.5568
TUNNEL Q (PSF) 10.228
TUNNEL VELOC (FPS) 93.59887025
```

67 PER CENT BLADES

```
PORT #  1
X/C=  0.352
PORT PRESS=  2086.53272
CP= -1.86

PORT #  2
X/C=  0.384
PORT PRESS=  2086.94184
CP= -1.82

PORT #  3
X/C=  0.416
PORT PRESS=  2087.55552
CP= -1.76

PORT #  4
X/C=  0.448
PORT PRESS=  2087.76008
CP= -1.74

PORT #  5
X/C=  0.48
PORT PRESS=  2087.96464
CP= -1.72

PORT #  6
X/C=  0.512
PORT PRESS=  2087.96464
CP= -1.72

PORT #  7
X/C=  0.544
PORT PRESS=  2087.96464
CP= -1.72

PORT #  8
X/C=  0.576
PORT PRESS=  2088.57832
CP= -1.66

PORT #  9
X/C=  0.608
PORT PRESS=  2087.55552
CP= -1.76

PORT #  10
X/C=  0.64
PORT PRESS=  2087.1464
CP= -1.8

PORT #  11
X/C=  0.672
PORT PRESS=  2085.1008
CP= -2

PORT #  12
X/C=  0.72
PORT PRESS=  2087.55552
CP= -1.76

PORT #  13
X/C=  0.736
PORT PRESS=  2088.57832
CP= -1.66

PORT #  14
X/C=  0.752
PORT PRESS=  2089.60112
CP= -1.56

PORT #  15
X/C=  0.768
PORT PRESS=  2090.41936
CP= -1.48

PORT #  16
X/C=  0.784
PORT PRESS=  2090.82848
CP= -1.44

PORT #  17
X/C=  0.8
PORT PRESS=  2091.2376
CP= -1.4

PORT #  18
X/C=  0.816
PORT PRESS=  2091.64672
CP= -1.36

PORT #  19
X/C=  0.832
PORT PRESS=  2092.2604
CP= -1.3

PORT #  20
X/C=  0.848
PORT PRESS=  2092.87408
CP= -1.24

PORT #  21
X/C=  0.864
PORT PRESS=  2092.87408
CP= -1.24

PORT #  22
X/C=  0.88
PORT PRESS=  2093.2832
CP= -1.2

PORT #  23
X/C=  0.896
PORT PRESS=  2093.48776
CP= -1.18

PORT #  24
X/C=  0.912
PORT PRESS=  2093.69232
CP= -1.16

PORT #  25
X/C=  0.928
PORT PRESS=  2094.10144
CP= -1.12

PORT #  26
X/C=  0.944
PORT PRESS=  2094.306
CP= -1.1

PORT #  27
X/C=  0.96
PORT PRESS=  2094.51056
CP= -1.08
```

TABLE III (continued)

MEASURED SURFACE PRESSURES

```
2    HZ
68   TEMP (F)
ATMOS PRESS (PSF) 2115.7848
TUNNEL PRESS (PSF) 2106.5796
TUNNEL Q (PSF) 9.2052
TUNNEL VELOC (FPS) 88.79568493

67 PER CENT BLADES

PORT #  1
X/C=  0.352
PORT PRESS=  2089.80568
CP= -1.822222222

PORT #  2
X/C=  0.384
PORT PRESS=  2090.41936
CP= -1.755555556

PORT #  3
X/C=  0.416
PORT PRESS=  2090.62392
CP= -1.733333333

PORT #  4
X/C=  0.448
PORT PRESS=  2091.03304
CP= -1.688888889

PORT #  5
X/C=  0.48
PORT PRESS=  2091.2376
CP= -1.666666667

PORT #  6
X/C=  0.512
PORT PRESS=  2091.2376
CP= -1.666666667

PORT #  7
X/C=  0.544
PORT PRESS=  2091.03304
CP= -1.688888889

PORT #  8
X/C=  0.576
PORT PRESS=  2091.64672
CP= -1.622222222

PORT #  9
X/C=  0.608
PORT PRESS=  2090.62392
CP= -1.733333333

PORT #  10
X/C=  0.64
PORT PRESS=  2090.2148
CP= -1.777777778

PORT #  11
X/C=  0.672
PORT PRESS=  2088.98744
CP= -1.911111111

PORT #  12
X/C=  0.72
PORT PRESS=  2090.62392
CP= -1.733333333

PORT #  13
X/C=  0.736
PORT PRESS=  2091.64672
CP= -1.622222222

PORT #  14
X/C=  0.752
PORT PRESS=  2092.2604
CP= -1.555555556

PORT #  15
X/C=  0.768
PORT PRESS=  2093.07864
CP= -1.466666667

PORT #  16
X/C=  0.784
PORT PRESS=  2093.69232
CP= -1.4

PORT #  17
X/C=  0.8
PORT PRESS=  2093.89688
CP= -1.377777778

PORT #  18
X/C=  0.816
PORT PRESS=  2094.306
CP= -1.333333333

PORT #  19
X/C=  0.832
PORT PRESS=  2095.12424
CP= -1.244444444

PORT #  20
X/C=  0.848
PORT PRESS=  2095.53336
CP= -1.2

PORT #  21
X/C=  0.864
PORT PRESS=  2095.73792
CP= -1.177777778

PORT #  22
X/C=  0.88
PORT PRESS=  2095.94248
CP= -1.155555556

PORT #  23
X/C=  0.896
PORT PRESS=  2095.94248
CP= -1.155555556

PORT #  24
X/C=  0.912
PORT PRESS=  2096.14704
CP= -1.133333333

PORT #  25
X/C=  0.928
PORT PRESS=  2096.3516
CP= -1.111111111

PORT #  26
X/C=  0.944
PORT PRESS=  2096.55616
CP= -1.088888889

PORT #  27
X/C=  0.96
PORT PRESS=  2096.76072
CP= -1.066666667
```

TABLE III (continued)

MEASURED SURFACE PRESSURE

```
 4    HZ
 68   TEMP (F)
ATMOS PRESS (PSF) 2115.7848
TUNNEL PRESS (PSF) 2108.01152
TUNNEL Q (PSF) 7.77328
TUNNEL VELOC (FPS) 61.59760333

67 PER CENT BLADE

PORT #  1
X/C=  0.352
PORT PRESS=  2093.48776
CP= -1.868421053

PORT #  2
X/C=  0.384
PORT PRESS=  2093.89688
CP= -1.815789474

PORT #  3
X/C=  0.416
PORT PRESS=  2094.306
CP= -1.763157895

PORT #  4
X/C=  0.448
PORT PRESS=  2094.71512
CP= -1.710526316

PORT #  5
X/C=  0.48
PORT PRESS=  2094.71512
CP= -1.710526316

PORT #  6
X/C=  0.512
PORT PRESS=  2094.71512
CP= -1.710526316

PORT #  7
X/C=  0.544
PORT PRESS=  2094.71512
CP= -1.710526316

PORT #  8
X/C=  0.576
PORT PRESS=  2095.12424
CP= -1.657894737

PORT #  9
X/C=  0.608
PORT PRESS=  2094.306
CP= -1.763157895

PORT #  10
X/C=  0.64
PORT PRESS=  2094.10144
CP= -1.789473684

PORT #  11
X/C=  0.672
PORT PRESS=  2092.87408
CP= -1.947368421

PORT #  12
X/C=  0.72
PORT PRESS=  2094.306
CP= -1.763157895

PORT #  13
X/C=  0.736
PORT PRESS=  2095.3288
CP= -1.631578947

PORT #  14
X/C=  0.752
PORT PRESS=  2095.94248
CP= -1.552631579

PORT #  15
X/C=  0.768
PORT PRESS=  2096.76072
CP= -1.447368421

PORT #  16
X/C=  0.784
PORT PRESS=  2096.96528
CP= -1.421052632

PORT #  17
X/C=  0.8
PORT PRESS=  2097.3744
CP= -1.368421053

PORT #  18
X/C=  0.816
PORT PRESS=  2097.57896
CP= -1.342105263

PORT #  19
X/C=  0.832
PORT PRESS=  2097.98808
CP= -1.289473684

PORT #  20
X/C=  0.848
PORT PRESS=  2098.80632
CP= -1.184210526

PORT #  21
X/C=  0.864
PORT PRESS=  2099.01088
CP= -1.157894737

PORT #  22
X/C=  0.88
PORT PRESS=  2099.21544
CP= -1.131578947

PORT #  23
X/C=  0.896
PORT PRESS=  2099.21544
CP= -1.131578947

PORT #  24
X/C=  0.912
PORT PRESS=  2099.42
CP= -1.105263158

PORT #  25
X/C=  0.928
PORT PRESS=  2099.62456
CP= -1.078947368

PORT #  26
X/C=  0.944
PORT PRESS=  2099.82912
CP= -1.052631579

PORT #  27
X/C=  0.96
PORT PRESS=  2099.82912
CP= -1.052631579
```

TABLE III (continued)

MEASURED SURFACE PRESSURES

```
 6    HZ
 68   TEMP (F)
ATMOS PRESS (PSF) 2115.7848
TUNNEL PRESS (PSF) 2108.01152
TUNNEL Q (PSF) 7.77328
TUNNEL VELOC (FPS) 81.59760333
```

67 PER CENT BLADE

```
PORT #  1
X/C=  0.352
PORT PRESS=  2093.69232
CP= -1.842105263

PORT #  2
X/C=  0.384
PORT PRESS=  2094.306
CP= -1.763157895

PORT #  3
X/C=  0.416
PORT PRESS=  2094.51056
CP= -1.736842105

PORT #  4
X/C=  0.448
PORT PRESS=  2094.71512
CP= -1.710526316

PORT #  5
X/C=  0.48
PORT PRESS=  2095.12424
CP= -1.657894737

PORT #  6
X/C=  0.512
PORT PRESS=  2094.91968
CP= -1.684210526

PORT #  7
X/C=  0.544
PORT PRESS=  2094.71512
CP= -1.710526316

PORT #  8
X/C=  0.576
PORT PRESS=  2095.53336
CP= -1.605263158

PORT #  9
X/C=  0.608
PORT PRESS=  2094.306
CP= -1.763157895

PORT #  10
X/C=  0.64
PORT PRESS=  2094.10144
CP= -1.789473684

PORT #  11
X/C=  0.672
PORT PRESS=  2092.87408
CP= -1.947368421

PORT #  12
X/C=  0.72
PORT PRESS=  2094.306
CP= -1.763157895

PORT #  13
X/C=  0.736
PORT PRESS=  2095.3288
CP= -1.631578947

PORT #  14
X/C=  0.752
PORT PRESS=  2095.94248
CP= -1.552631579

PORT #  15
X/C=  0.768
PORT PRESS=  2096.3516
CP= -1.5

PORT #  16
X/C=  0.784
PORT PRESS=  2096.76072
CP= -1.447368421

PORT #  17
X/C=  0.8
PORT PRESS=  2097.16984
CP= -1.394736842

PORT #  18
X/C=  0.816
PORT PRESS=  2097.57896
CP= -1.342105263

PORT #  19
X/C=  0.832
PORT PRESS=  2098.3972
CP= -1.236842105

PORT #  20
X/C=  0.848
PORT PRESS=  2098.80632
CP= -1.184210526

PORT #  21
X/C=  0.864
PORT PRESS=  2098.80632
CP= -1.184210526

PORT #  22
X/C=  0.88
PORT PRESS=  2099.42
CP= -1.105263158

PORT #  23
X/C=  0.896
PORT PRESS=  2099.42
CP= -1.105263158

PORT #  24
X/C=  0.912
PORT PRESS=  2099.42
CP= -1.105263158

PORT #  25
X/C=  0.928
PORT PRESS=  2099.62456
CP= -1.078947368

PORT #  26
X/C=  0.944
PORT PRESS=  2099.62456
CP= -1.078947368

PORT #  27
X/C=  0.96
PORT PRESS=  2099.82912
CP= -1.052631579
```

TABLE III (continued)

MEASURED SURFACE PRESSURES

25 HZ
68 TEMP (F)
ATMOS PRESS (PSF) 2115.7848
TUNNEL PRESS (PSF) 2106.5796
TUNNEL Q (PSF) 9.2052
TUNNEL VELOC (FPS) 88.79568493

67 PER CENT BLADES

PORT #	X/C=	PORT PRESS=	CP=
1	0.352	2090.62392	-1.733333333
2	0.384	2090.82848	-1.711111111
3	0.416	2091.03304	-1.688888889
4	0.448	2091.2376	-1.666666667
5	0.48	2091.44216	-1.644444444
6	0.512	2091.64672	-1.622222222
7	0.544	2091.85128	-1.6
8	0.576	2092.2604	-1.555555556
9	0.608	2091.03304	-1.688888889
10	0.64	2090.62392	-1.733333333
11	0.672	2089.60112	-1.844444444
12	0.72	2091.03304	-1.688888889
13	0.736	2092.2604	-1.555555556
14	0.752	2093.07864	-1.466666667
15	0.768	2093.69232	-1.4
16	0.784	2094.10144	-1.355555556
17	0.8	2094.71512	-1.288888889
18	0.816	2094.71512	-1.288888889
19	0.832	2095.12424	-1.244444444
20	0.848	2095.73792	-1.177777778
21	0.864	2095.73792	-1.177777778
22	0.88	2095.73792	-1.177777778
23	0.896	2095.94248	-1.155555556
24	0.912	2096.14704	-1.133333333
25	0.928	2096.3516	-1.111111111
26	0.944	2096.76072	-1.066666667
27	0.96	2096.76072	-1.066666667

TABLE III (continued)

MEASURED SURFACE PRESSURES

```
 30   HZ
 68   TEMP (F)
ATMOS PRESS (PSF) 2115.7848
TUNNEL PRESS (PSF) 2105.5568
TUNNEL Q (PSF) 10.228
TUNNEL VELOC (FPS) 93.59887025

67 PER CENT BLADES

PORT #  1
X/C=  0.352
PORT PRESS=  2089.60112
CP= -1.56

PORT #  2
X/C=  0.384
PORT PRESS=  2090.01024
CP= -1.52

PORT #  3
X/C=  0.416
PORT PRESS=  2090.41936
CP= -1.48

PORT #  4
X/C=  0.448
PORT PRESS=  2090.62392
CP= -1.46

PORT #  5
X/C=  0.48
PORT PRESS=  2090.62392
CP= -1.46

PORT #  6
X/C=  0.512
PORT PRESS=  2090.62392
CP= -1.46

PORT #  7
X/C=  0.544
PORT PRESS=  2090.62392
CP= -1.46

PORT #  8
X/C=  0.576
PORT PRESS=  2091.03304
CP= -1.42

PORT #  9
X/C=  0.608
PORT PRESS=  2089.60112
CP= -1.56

PORT #  10
X/C=  0.64
PORT PRESS=  2089.60112
CP= -1.56

PORT #  11
X/C=  0.672
PORT PRESS=  2087.55552
CP= -1.76

PORT #  12
X/C=  0.72
PORT PRESS=  2089.60112
CP= -1.56

PORT #  13
X/C=  0.736
PORT PRESS=  2091.2376
CP= -1.4

PORT #  14
X/C=  0.752
PORT PRESS=  2091.64672
CP= -1.36

PORT #  15
X/C=  0.768
PORT PRESS=  2092.05584
CP= -1.32

PORT #  16
X/C=  0.784
PORT PRESS=  2092.46496
CP= -1.28

PORT #  17
X/C=  0.8
PORT PRESS=  2093.2832
CP= -1.2

PORT #  18
X/C=  0.816
PORT PRESS=  2093.69232
CP= -1.16

PORT #  19
X/C=  0.832
PORT PRESS=  2094.10144
CP= -1.12

PORT #  20
X/C=  0.848
PORT PRESS=  2094.71512
CP= -1.06

PORT #  21
X/C=  0.864
PORT PRESS=  2094.71512
CP= -1.06

PORT #  22
X/C=  0.88
PORT PRESS=  2094.91968
CP= -1.04

PORT #  23
X/C=  0.896
PORT PRESS=  2094.91968
CP= -1.04

PORT #  24
X/C=  0.912
PORT PRESS=  2095.12424
CP= -1.02

PORT #  25
X/C=  0.928
PORT PRESS=  2095.12424
CP= -1.02

PORT #  26
X/C=  0.944
PORT PRESS=  2095.3288
CP= -1

PORT #  27
X/C=  0.96
PORT PRESS=  2095.73792
CP= -0.96
```

TABLE III (continued)

MEASURED SURFACE PRESSURES

```
 40   HZ
 68   TEMP (F)
ATMOS PRESS (PSF) 2115.7848
TUNNEL PRESS (PSF) 2106.5796
TUNNEL Q (PSF) 9.2052
TUNNEL VELOC (FPS) 88.79568493
```

67 PER CENT BLADES

```
PORT #  1
X/C=  0.352
PORT PRESS=  2092.66952
CP= -1.511111111

PORT #  2
X/C=  0.384
PORT PRESS=  2092.87408
CP= -1.488888889

PORT #  3
X/C=  0.416
PORT PRESS=  2093.07864
CP= -1.466666667

PORT #  4
X/C=  0.448
PORT PRESS=  2093.48776
CP= -1.422222222

PORT #  5
X/C=  0.48
PORT PRESS=  2093.69232
CP= -1.4

PORT #  6
X/C=  0.512
PORT PRESS=  2093.69232
CP= -1.4

PORT #  7
X/C=  0.544
PORT PRESS=  2093.69232
CP= -1.4

PORT #  8
X/C=  0.576
PORT PRESS=  2094.306
CP= -1.333333333

PORT #  9
X/C=  0.608
PORT PRESS=  2093.07864
CP= -1.466666667

PORT #  10
X/C=  0.64
PORT PRESS=  2092.66952
CP= -1.511111111

PORT #  11
X/C=  0.672
PORT PRESS=  2091.64672
CP= -1.622222222

PORT #  12
X/C=  0.72
PORT PRESS=  2092.66952
CP= -1.511111111

PORT #  13
X/C=  0.736
PORT PRESS=  2093.69232
CP= -1.4

PORT #  14
X/C=  0.752
PORT PRESS=  2094.71512
CP= -1.288888889

PORT #  15
X/C=  0.768
PORT PRESS=  2095.12424
CP= -1.244444444

PORT #  16
X/C=  0.784
PORT PRESS=  2095.3288
CP= -1.222222222

PORT #  17
X/C=  0.8
PORT PRESS=  2095.73792
CP= -1.177777778

PORT #  18
X/C=  0.816
PORT PRESS=  2096.3516
CP= -1.111111111

PORT #  19
X/C=  0.832
PORT PRESS=  2096.76072
CP= -1.066666667

PORT #  20
X/C=  0.848
PORT PRESS=  2096.96528
CP= -1.044444444

PORT #  21
X/C=  0.864
PORT PRESS=  2097.16984
CP= -1.022222222

PORT #  22
X/C=  0.88
PORT PRESS=  2097.57896
CP= -0.977777778

PORT #  23
X/C=  0.896
PORT PRESS=  2097.78352
CP= -0.955555556

PORT #  24
X/C=  0.912
PORT PRESS=  2097.78352
CP= -0.955555556

PORT #  25
X/C=  0.928
PORT PRESS=  2097.98808
CP= -0.933333333

PORT #  26
X/C=  0.944
PORT PRESS=  2098.19264
CP= -0.911111111

PORT #  27
X/C=  0.96
PORT PRESS=  2098.3972
CP= -0.888888889
```

TABLE III (continued)

MEASURED SURFACE PRESSURES

50 HZ
68 TEMP (F)
ATMOS PRESS (PSF) 2115.7848
TUNNEL PRESS (PSF) 2105.5568
TUNNEL Q (PSF) 10.228
TUNNEL VELOC (FPS) 93.59887025

67 PER CENT BLADES

PORT #	X/C=	PORT PRESS=	CP=
1	0.352	2088.57832	-1.66
2	0.384	2088.98744	-1.62
3	0.416	2089.192	-1.6
4	0.448	2089.60112	-1.56
5	0.48	2090.01024	-1.52
6	0.512	2090.01024	-1.52
7	0.544	2090.01024	-1.52
8	0.576	2090.82848	-1.44
9	0.608	2089.60112	-1.56
10	0.64	2089.192	-1.6
11	0.672	2087.96464	-1.72
12	0.72	2090.01024	-1.52
13	0.736	2091.03304	-1.42
14	0.752	2091.64672	-1.36
15	0.768	2092.66952	-1.26
16	0.784	2092.87408	-1.24
17	0.8	2093.2832	-1.2
18	0.816	2093.69232	-1.16
19	0.832	2094.51056	-1.08
20	0.848	2094.71512	-1.06
21	0.864	2094.91968	-1.04
22	0.88	2095.12424	-1.02
23	0.896	2095.3288	-1
24	0.912	2095.73792	-0.96
25	0.928	2096.14704	-0.92
26	0.944	2096.3516	-0.9
27	0.96	2096.55616	-0.88

TABLE III (continued)

MEASURED SURFACE PRESSURES

67 PER CENT BLADES

60 HZ
63 TEMP (F)
ATMOS PRESS (PSF) 2115.7848
TUNNEL PRESS (PSF) 2108.01152
TUNNEL Q (PSF) 7.77328
TUNNEL VELOC (FPS) 81.59760333

PORT # 1 X/C= 0.352 PORT PRESS= 2094.10144 CP= -1.789473684	PORT # 10 X/C= 0.64 PORT PRESS= 2094.51056 CP= -1.736842105	PORT # 19 X/C= 0.832 PORT PRESS= 2098.60176 CP= -1.210526316
PORT # 2 X/C= 0.384 PORT PRESS= 2094.51056 CP= -1.736842105	PORT # 11 X/C= 0.672 PORT PRESS= 2093.2832 CP= -1.894736842	PORT # 20 X/C= 0.848 PORT PRESS= 2098.80632 CP= -1.184210526
PORT # 3 X/C= 0.416 PORT PRESS= 2094.71512 CP= -1.710526316	PORT # 12 X/C= 0.72 PORT PRESS= 2094.71512 CP= -1.710526316	PORT # 21 X/C= 0.864 PORT PRESS= 2098.80632 CP= -1.184210526
PORT # 4 X/C= 0.448 PORT PRESS= 2094.91968 CP= -1.684210526	PORT # 13 X/C= 0.736 PORT PRESS= 2095.73792 CP= -1.578947368	PORT # 22 X/C= 0.88 PORT PRESS= 2099.01088 CP= -1.157894737
PORT # 5 X/C= 0.48 PORT PRESS= 2095.12424 CP= -1.657894737	PORT # 14 X/C= 0.752 PORT PRESS= 2096.55616 CP= -1.47368421 -	PORT # 23 X/C= 0.896 PORT PRESS= 2099.21544 CP= -1.131578947
PORT # 6 X/C= 0.512 PORT PRESS= 2095.12424 CP= -1.657894737	PORT # 15 X/C= 0.768 PORT PRESS= 2096.96528 CP= -1.421052632	PORT # 24 X/C= 0.912 PORT PRESS= 2099.21544 CP= -1.131578947
PORT # 7 X/C= 0.544 PORT PRESS= 2095.12424 CP= -1.657894737	PORT # 16 X/C= 0.784 PORT PRESS= 2097.16984 CP= -1.394736842	PORT # 25 X/C= 0.928 PORT PRESS= 2099.42 CP= -1.105263158
PORT # 8 X/C= 0.576 PORT PRESS= 2095.73792 CP= -1.578947368	PORT # 17 X/C= 0.8 PORT PRESS= 2097.3744 CP= -1.368421053	PORT # 26 X/C= 0.944 PORT PRESS= 2099.42 CP= -1.105263158
PORT # 9 X/C= 0.608 PORT PRESS= 2094.71512 CP= -1.710526316	PORT # 18 X/C= 0.816 PORT PRESS= 2098.19264 CP= -1.263157895	PORT # 27 X/C= 0.96 PORT PRESS= 2099.82912 CP= -1.052631579

TABLE III (continued)

MEASURED SURFACE PRESSURES

```
70   HZ
68   TEMP (F)
ATMOS PRESS (PSF) 2115.7848
TUNNEL PRESS (PSF) 2108.01152
TUNNEL Q (PSF) 7.77328
TUNNEL VELOC (FPS) 81.59760333
```

67 PER CENT BLADES

```
PORT #  1
X/C=  0.352
PORT PRESS=  2094.10144
CP= -1.789473684

PORT #  2
X/C=  0.384
PORT PRESS=  2094.51056
CP= -1.736842105

PORT #  3
X/C=  0.416
PORT PRESS=  2095.12424
CP= -1.657894737

PORT #  4
X/C=  0.448
PORT PRESS=  2095.3288
CP= -1.631578947

PORT #  5
X/C=  0.48
PORT PRESS=  2095.3288
CP= -1.631578947

PORT #  6
X/C=  0.512
PORT PRESS=  2095.3288
CP= -1.631578947

PORT #  7
X/C=  0.544
PORT PRESS=  2095.3288
CP= -1.631578947

PORT #  8
X/C=  0.576
PORT PRESS=  2096.14704
CP= -1.526315789

PORT #  9
X/C=  0.608
PORT PRESS=  2094.91968
CP= -1.684210526

PORT #  10
X/C=  0.64
PORT PRESS=  2094.51056
CP= -1.736842105

PORT #  11
X/C=  0.672
PORT PRESS=  2093.69232
CP= -1.842105263

PORT #  12
X/C=  0.72
PORT PRESS=  2094.91968
CP= -1.684210526

PORT #  13
X/C=  0.736
PORT PRESS=  2095.73792
CP= -1.578947368

PORT #  14
X/C=  0.752
PORT PRESS=  2096.55616
CP= -1.47368421

PORT #  15
X/C=  0.768
PORT PRESS=  2096.96528
CP= -1.421052632

PORT #  16
X/C=  0.784
PORT PRESS=  2097.3744
CP= -1.368421053

PORT #  17
X/C=  0.8
PORT PRESS=  2097.78352
CP= -1.315789474

PORT #  18
X/C=  0.816
PORT PRESS=  2098.19264
CP= -1.263157895

PORT #  19
X/C=  0.832
PORT PRESS=  2098.60176
CP= -1.210526316

PORT #  20
X/C=  0.848
PORT PRESS=  2099.01088
CP= -1.157894737

PORT #  21
X/C=  0.864
PORT PRESS=  2099.01088
CP= -1.157894737

PORT #  22
X/C=  0.88
PORT PRESS=  2099.01088
CP= -1.157894737

PORT #  23
X/C=  0.896
PORT PRESS=  2099.21544
CP= -1.131578947

PORT #  24
X/C=  0.912
PORT PRESS=  2099.42
CP= -1.105263158

PORT #  25
X/C=  0.928
PORT PRESS=  2099.42
CP= -1.105263158

PORT #  26
X/C=  0.944
PORT PRESS=  2099.62456
CP= -1.078947368

PORT #  27
X/C=  0.96
PORT PRESS=  2099.82912
CP= -1.052631579
```

TABLE III (continued)

MEASURED SURFACE PRESSURES

```
 80   HZ
 68   TEMP (F)
ATMOS PRESS (PSF) 2115.7848
TUNNEL PRESS (PSF) 2103.92032
TUNNEL Q (PSF) 11.86448
TUNNEL VELOC (FPS) 100.8090684
```

67 PER CENT BLADES

```
PORT #  1                     PORT #  10                    PORT #  19
X/C=  0.352                   X/C=  0.64                    X/C=  0.832
PORT PRESS=  2088.37376       PORT PRESS=  2087.96464       PORT PRESS=  2092.05584
CP= -1.310344828              CP= -1.344827586              CP= -1

PORT #  2                     PORT #  11                    PORT #  20
X/C=  0.384                   X/C=  0.672                   X/C=  0.848
PORT PRESS=  2088.78288       PORT PRESS=  2086.32816       PORT PRESS=  2092.46496
CP= -1.275862069              CP= -1.482758862              CP= -0.965517241

PORT #  3                     PORT #  12                    PORT #  21
X/C=  0.416                   X/C=  0.72                    X/C=  0.864
PORT PRESS=  2089.192         PORT PRESS=  2087.55552       PORT PRESS=  2092.46496
CP= -1.24137931               CP= -1.379310345              CP= -0.965517241

PORT #  4                     PORT #  13                    PORT #  22
X/C=  0.448                   X/C=  0.736                   X/C=  0.88
PORT PRESS=  2089.60112       PORT PRESS=  2088.98744       PORT PRESS=  2092.66952
CP= -1.206896552              CP= -1.258620690              CP= -0.948275862

PORT #  5                     PORT #  14                    PORT #  23
X/C=  0.48                    X/C=  0.752                   X/C=  0.896
PORT PRESS=  2089.60112       PORT PRESS=  2089.60112       PORT PRESS=  2092.87408
CP= -1.206896552              CP= -1.206896552              CP= -0.931034483

PORT #  6                     PORT #  15                    PORT #  24
X/C=  0.512                   X/C=  0.768                   X/C=  0.912
PORT PRESS=  2089.60112       PORT PRESS=  2090.01024       PORT PRESS=  2093.07864
CP= -1.206896552              CP= -1.172413793              CP= -0.913793103

PORT #  7                     PORT #  16                    PORT #  25
X/C=  0.544                   X/C=  0.784                   X/C=  0.928
PORT PRESS=  2089.60112       PORT PRESS=  2090.41936       PORT PRESS=  2093.2832
CP= -1.206896552              CP= -1.137931034              CP= -0.896551724

PORT #  8                     PORT #  17                    PORT #  26
X/C=  0.576                   X/C=  0.8                     X/C=  0.944
PORT PRESS=  2090.01024       PORT PRESS=  2091.03304       PORT PRESS=  2093.2832
CP= -1.172413793              CP= -1.086206897              CP= -0.896551724

PORT #  9                     PORT #  18                    PORT #  27
X/C=  0.608                   X/C=  0.816                   X/C=  0.96
PORT PRESS=  2088.37376       PORT PRESS=  2091.44216       PORT PRESS=  2093.69232
CP= -1.310344828              CP= -1.051724138              CP= -0.862068966
```

TABLE III (continued)

MEASURED SURFACE PRESSURES

```
 90   HZ
 68   TEMP (F)
ATMOS PRESS (PSF) 2115.7848
TUNNEL PRESS (PSF) 2106.5796
TUNNEL Q (PSF) 9.2052
TUNNEL VELOC (FPS) 88.79568493
```

67 PER CENT BLADES

```
PORT #  1
X/C=  0.352
PORT PRESS=  2092.2604
CP= -1.555555556

PORT #  2
X/C=  0.384
PORT PRESS=  2092.66952
CP= -1.511111111

PORT #  3
X/C=  0.416
PORT PRESS=  2093.07864
CP= -1.466666667

PORT #  4
X/C=  0.448
PORT PRESS=  2093.2832
CP= -1.444444444

PORT #  5
X/C=  0.48
PORT PRESS=  2093.69232
CP= -1.4

PORT #  6
X/C=  0.512
PORT PRESS=  2093.48776
CP= -1.422222222

PORT #  7
X/C=  0.544
PORT PRESS=  2093.48776
CP= -1.422222222

PORT #  8
X/C=  0.576
PORT PRESS=  2093.89688
CP= -1.377777778

PORT #  9
X/C=  0.608
PORT PRESS=  2092.66952
CP= -1.511111111

PORT #  10
X/C=  0.64
PORT PRESS=  2092.66952
CP= -1.511111111

PORT #  11
X/C=  0.672
PORT PRESS=  2091.44216
CP= -1.644444444

PORT #  12
X/C=  0.72
PORT PRESS=  2093.07864
CP= -1.466666667

PORT #  13
X/C=  0.736
PORT PRESS=  2094.10144
CP= -1.355555556

PORT #  14
X/C=  0.752
PORT PRESS=  2094.71512
CP= -1.288888889

PORT #  15
X/C=  0.768
PORT PRESS=  2095.12424
CP= -1.244444444

PORT #  16
X/C=  0.784
PORT PRESS=  2095.53336
CP= -1.2

PORT #  17
X/C=  0.8
PORT PRESS=  2095.94248
CP= -1.155555556

PORT #  18
X/C=  0.816
PORT PRESS=  2096.3516
CP= -1.111111111

PORT #  19
X/C=  0.832
PORT PRESS=  2096.76072
CP= -1.066666667

PORT #  20
X/C=  0.848
PORT PRESS=  2097.16984
CP= -1.022222222

PORT #  21
X/C=  0.864
PORT PRESS=  2097.16984
CP= -1.022222222

PORT #  22
X/C=  0.88
PORT PRESS=  2097.57896
CP= -0.977777778

PORT #  23
X/C=  0.896
PORT PRESS=  2097.57896
CP= -0.977777778

PORT #  24
X/C=  0.912
PORT PRESS=  2097.57896
CP= -0.977777778

PORT #  25
X/C=  0.928
PORT PRESS=  2097.78352
CP= -0.955555556

PORT #  26
X/C=  0.944
PORT PRESS=  2097.98808
CP= -0.933333333

PORT #  27
X/C=  0.96
PORT PRESS=  2098.3972
CP= -0.888888889
```

TABLE III (continued)

MEASURED SURFACE PRESSURES

```
100  HZ
68   TEMP (F)
ATMOS PRESS (PSF) 2115.7848
TUNNEL PRESS (PSF) 2108.01152
TUNNEL Q (PSF) 7.77328
TUNNEL VELOC (FPS) 81.59760333

67 PER CENT BLADE

PORT #  1
X/C=  0.352
PORT PRESS=  2094.10144
CP= -1.789473684

PORT #  2
X/C=  0.384
PORT PRESS=  2094.51056
CP= -1.736842105

PORT #  3
X/C=  0.416
PORT PRESS=  2094.71512
CP= -1.710526316

PORT #  4
X/C=  0.448
PORT PRESS=  2094.91968
CP= -1.684210526

PORT #  5
X/C=  0.48
PORT PRESS=  2095.3288
CP= -1.631578947

PORT #  6
X/C=  0.512
PORT PRESS=  2095.12424
CP= -1.657894737

PORT #  7
X/C=  0.544
PORT PRESS=  2095.12424
CP= -1.657894737

PORT #  8
X/C=  0.576
PORT PRESS=  2095.73792
CP= -1.578947368

PORT #  9
X/C=  0.608
PORT PRESS=  2094.71512
CP= -1.710526316

PORT #  10
X/C=  0.64
PORT PRESS=  2094.51056
CP= -1.736842105

PORT #  11
X/C=  0.672
PORT PRESS=  2093.69232
CP= -1.842105263

PORT #  12
X/C=  0.72
PORT PRESS=  2094.91968
CP= -1.684210526

PORT #  13
X/C=  0.736
PORT PRESS=  2095.94248
CP= -1.552631579

PORT #  14
X/C=  0.752
PORT PRESS=  2096.3516
CP= -1.5

PORT #  15
X/C=  0.768
PORT PRESS=  2096.96528
CP= -1.421052632

PORT #  16
X/C=  0.784
PORT PRESS=  2097.16984
CP= -1.394736842

PORT #  17
X/C=  0.8
PORT PRESS=  2097.78352
CP= -1.315789474

PORT #  18
X/C=  0.816
PORT PRESS=  2098.19264
CP= -1.263157895

PORT #  19
X/C=  0.832
PORT PRESS=  2098.60176
CP= -1.210526316

PORT #  20
X/C=  0.848
PORT PRESS=  2099.01088
CP= -1.157894737

PORT #  21
X/C=  0.864
PORT PRESS=  2099.01088
CP= -1.157894737

PORT #  22
X/C=  0.88
PORT PRESS=  2099.21544
CP= -1.131578947

PORT #  23
X/C=  0.896
PORT PRESS=  2099.21544
CP= -1.131578947

PORT #  24
X/C=  0.912
PORT PRESS=  2099.42
CP= -1.105263158

PORT #  25
X/C=  0.928
PORT PRESS=  2099.62456
CP= -1.078947368

PORT #  26
X/C=  0.944
PORT PRESS=  2099.62456
CP= -1.078947368

PORT #  27
X/C=  0.96
PORT PRESS=  2099.82912
CP= -1.052631579
```

TABLE III (continued)

MEASURED SURFACE PRESSURES

```
 2    HZ
 72   TEMP (F)
ATMOS PRESS (PSF) 2121.426893
TUNNEL PRESS (PSF) 2117.335693
TUNNEL Q (PSF) 4.0912
TUNNEL VELOC (FPS) 59.34186193
```

98 PER CENT BLADES

PORT #	X/C=	PORT PRESS=	CP=
1	0.352	2109.153293	-2
2	0.384	2109.357853	-1.95
3	0.416	2109.766973	-1.85
4	0.448	2110.176093	-1.75
5	0.48	2110.176093	-1.75
6	0.512	2110.176093	-1.75
7	0.544	2110.176093	-1.75
8	0.576	2110.585213	-1.65
9	0.608	2109.971533	-1.8
10	0.64	2109.971533	-1.8
11	0.672	2109.153293	-2
12	0.72	2109.971533	-1.8
13	0.736	2110.585213	-1.65
14	0.752	2110.789773	-1.6
15	0.768	2111.198893	-1.5
16	0.784	2111.403453	-1.45
17	0.8	2111.403453	-1.45
18	0.816	2111.812573	-1.35
19	0.832	2111.812573	-1.35
20	0.848	2112.221693	-1.25
21	0.864	2112.221693	-1.25
22	0.88	2112.630813	-1.15
23	0.896	2112.630813	-1.15
24	0.913	2112.630813	-1.15
25	0.928	2113.039933	-1.05
26	0.944	2113.039933	-1.05
27	0.96	2113.244493	-1

TABLE III (continued)

MEASURED SURFACE PRESSURES

```
 4    HZ
 72   TEMP (F)
ATMOS PRESS (PSF) 2121.426893
TUNNEL PRESS (PSF) 2120.404093
TUNNEL Q (PSF) 1.0228
TUNNEL VELOC (FPS) 29.67093096
```

98 PER CENT BLADES

```
PORT #  1
X/C=  0.352
PORT PRESS=  2119.790413
CP= -2.6

PORT    2
X/C=  0.384
PORT PRESS=  2117.949373
CP= -2.4

PORT #  3
X/C=  0.416
PORT PRESS=  2118.153933
CP= -2.2

PORT #  4
X/C=  0.448
PORT PRESS=  2118.358493
CP= -2

PORT #  5
X/C=  0.48
PORT PRESS=  2118.358493
CP= -2

PORT #  6
X/C=  0.512
PORT PRESS=  2118.358493
CP= -2

PORT #  7
X/C=  0.544
PORT PRESS=  2118.358493
CP= -2

PORT #  8
X/C=  0.576
PORT PRESS=  2118.358493
CP= -2

PORT #  9
X/C=  0.608
PORT PRESS=  2118.358493
CP= -2

PORT #  10
X/C=  0.64
PORT PRESS=  2118.358493
CP= -2

PORT #  11
X/C=  0.672
PORT PRESS=  2118.358493
CP= -2

PORT #  12
X/C=  0.72
PORT PRESS=  2118.563053
CP= -1.8

PORT #  13
X/C=  0.736
PORT PRESS=  2118.767613
CP= -1.4

PORT #  14
X/C=  0.752
PORT PRESS=  2119.176733
CP= -1.2

PORT #  15
X/C=  0.768
PORT PRESS=  2119.176733
CP= -1.2

PORT #  16
X/C=  0.784
PORT PRESS=  2119.381293
CP= -1

PORT #  17
X/C=  0.8
PORT PRESS=  2119.381293
CP= -1

PORT #  18
X/C=  0.816
PORT PRESS=  2118.972173
CP= -1.4

PORT #  19
X/C=  0.832
PORT PRESS=  2119.381293
CP= -1

PORT #  20
X/C=  0.848
PORT PRESS=  2119.790413
CP  -0.6

PORT #  21
X/C=  0.864
PORT PRESS=  2119.790413
CP= -0.6

PORT #  22
X/C=  0.88
PORT PRESS=  2119.790413
CP= -0.6

PORT #  23
X/C=  0.896
PORT PRESS=  2119.994973
CP= -0.4

PORT #  24
X/C=  0.912
PORT PRESS=  2119.994973
CP= -0.4

PORT #  25
X/C=  0.928
PORT PRESS=  2119.994973
CP= -0.4

PORT #  26
X/C=  0.944
PORT PRESS=  2119.994973
CP= -0.4

PORT #  27
X/C=  0.96
PORT PRESS=  2120.199533
CP= -0.2
```

TABLE III (continued)

MEASURED SURFACE PRESSURES

98 PER CENT BLADES

```
6    HZ
72   TEMP (F)
ATMOS PRESS (PSF) 2121.426893
TUNNEL PRESS (PSF) 2120.404093
TUNNEL Q (PSF) 1.0228
TUNNEL VELOC (FPS) 29.67093096

PORT #  1
X/C=  0.352
PORT PRESS=  2118.972173
CP= -1.4

PORT #  2
X/C=  0.384
PORT PRESS=  2119.176733
CP= -1.2

PORT #  3
X/C=  0.416
PORT PRESS=  2119.381293
CP= -1

PORT #  4
X/C=  0.448
PORT PRESS=  2119.381293
CP= -1

PORT #  5
X/C=  0.48
PORT PRESS=  2119.381293
CP= -1

PORT #  6
X/C=  0.512
PORT PRESS=  2119.381293
CP= -1

PORT #  7
X/C=  0.544
PORT PRESS=  2119.381293
CP= -1

PORT #  8
X/C=  0.576
PORT PRESS=  2119.381293
CP= -1

PORT #  9
X/C=  0.608
PORT PRESS=  2119.381293
CP= -1

PORT #  10
X/C=  0.64
PORT PRESS=  2119.381293
CP= -1

PORT #  11
X/C=  0.672
PORT PRESS=  2119.381293
CP= -1

PORT #  12
X/C=  0.72
PORT PRESS=  2119.381293
CP= -1

PORT #  13
X/C=  0.736
PORT PRESS=  2119.790413
CP= -0.6

PORT #  14
X/C=  0.752
PORT PRESS=  2119.790413
CP= -0.6

PORT #  15
X/C=  0.768
PORT PRESS=  2119.790413
CP= -0.6

PORT #  16
X/C=  0.784
PORT PRESS=  2119.790413
CP= -0.6

PORT #  17
X/C=  0.8
PORT PRESS=  2119.790413
CP= -0.6

PORT #  18
X/C=  0.816
PORT PRESS=  2119.381293
CP= -1

PORT #  19
X/C=  0.832
PORT PRESS=  2120.404093
CP=  0

PORT #  20
X/C=  0.848
PORT PRESS=  2120.404093
CP=  0

PORT #  21
X/C=  0.864
PORT PRESS=  2120.404093
CP=  0

PORT #  22
X/C=  0.88
PORT PRESS=  2120.608653
CP=  0.2

PORT #  23
X/C=  0.896
PORT PRESS=  2120.608653
CP=  0.2

PORT #  24
X/C=  0.912
PORT PRESS=  2120.608653
CP=  0.2

PORT #  25
X/C=  0.928
PORT PRESS=  2120.608653
CP=  0.2

PORT #  26
X/C=  0.944
PORT PRESS=  2120.813213
CP=  0.4

PORT #  27
X/C=  0.96
PORT PRESS=  2120.813213
CP=  0.4
```

TABLE III (continued)

MEASURED SURFACE PRESSURES

```
 25   HZ
 65   TEMP (F)
ATMOS PRESS (PSF) 2120.016370
TUNNEL PRESS (PSF) 2117.970770
TUNNEL Q (PSF) 2.0456
TUNNEL VELOC (FPS) 41.69792408
```

98 PER CENT BLADES

PORT #	X/C=	PORT PRESS=	CP=
1	0.352	2114.902370	-1.5
2	0.384	2114.902370	-1.5
3	0.416	2114.902370	-1.5
4	0.448	2114.902370	-1.5
5	0.48	2114.902370	-1.5
6	0.512	2114.902370	-1.5
7	0.544	2114.902370	-1.5
8	0.576	2114.902370	-1.5
9	0.608	2114.902370	-1.5
10	0.64	2114.902370	-1.5
11	0.672	2113.879570	-2
12	0.72	2114.697810	-1.6
13	0.736	2114.902370	-1.5
14	0.752	2115.106930	-1.4
15	0.768	2115.516050	-1.2
16	0.784	2115.516050	-1.2
17	0.8	2115.516050	-1.2
18	0.816	2115.516050	-1.2
19	0.832	2115.516050	-1.2
20	0.848	2115.925170	-1
21	0.864	2115.925170	-1
22	0.88	2115.925170	-1
23	0.896	2116.129730	-0.9
24	0.912	2116.129730	-0.9
25	0.928	2116.129730	-0.9
26	0.944	2116.129730	-0.9
27	0.96	2116.334290	-0.8

TABLE III (continued)

MEASURED SURFACE PRESSURES

```
 30   HZ
 65   TEMP (F)
ATMOS PRESS (PSF) 2120.016370
TUNNEL PRESS (PSF) 2115.925170
TUNNEL Q (PSF) 4.0912
TUNNEL VELOC (FPS) 58.96976976
```

98 PER CENT BLADES

```
PORT #  1
X/C=  0.352
PORT PRESS=  2112.856770
CP= -0.75

PORT #  2
X/C=  0.384
PORT PRESS=  2112.856770
CP= -0.75

PORT #  3
X/C=  0.416
PORT PRESS=  2112.856770
CP= -0.75

PORT #  4
X/C=  0.448
PORT PRESS=  2112.856770
CP= -0.75

PORT #  5
X/C=  0.48
PORT PRESS=  2112.856770
CP= -0.75

PORT #  6
X/C=  0.512
PORT PRESS=  2112.856770
CP= -0.75

PORT #  7
X/C=  0.544
PORT PRESS=  2112.856770
CP= -0.75

PORT #  8
X/C=  0.576
PORT PRESS=  2112.856770
CP= -0.75

PORT #  9
X/C=  0.608
PORT PRESS=  2112.856770
CP= -0.75

PORT #  10
X/C=  0.64
PORT PRESS=  2112.856770
CP= -0.75

PORT #  11
X/C=  0.672
PORT PRESS=  2112.856770
CP= -0.75

PORT #  12
X/C=  0.72
PORT PRESS=  2112.856770
CP= -0.75

PORT #  13
X/C=  0.736
PORT PRESS=  2113.061330
CP= -0.7

PORT #  14
X/C=  0.752
PORT PRESS=  2113.061330
CP= -0.7

PORT #  15
X/C=  0.768
PORT PRESS=  2113.061330
CP= -0.7

PORT #  16
X/C=  0.784
PORT PRESS=  2113.265890
CP= -0.65

PORT #  17
X/C=  0.8
PORT PRESS=  2113.265890
CP= -0.65

PORT #  18
X/C=  0.816
PORT PRESS=  2113.265890
CP= -0.65

PORT #  19
X/C=  0.832
PORT PRESS=  2113.265890
CP= -0.65

PORT #  20
X/C=  0.848
PORT PRESS=  2113.470450
CP= -0.6

PORT #  21
X/C=  0.864
PORT PRESS=  2113.470450
CP= -0.6

PORT #  22
X/C=  0.88
PORT PRESS=  2113.470450
CP= -0.6

PORT #  23
X/C=  0.896
PORT PRESS=  2113.470450
CP= -0.6

PORT #  24
X/C=  0.912
PORT PRESS=  2113.470450
CP= -0.6

PORT #  25
X/C=  0.928
PORT PRESS=  2113.470450
CP= -0.6

PORT #  26
X/C=  0.944
PORT PRESS=  2113.470450
CP= -0.6

PORT #  27
X/C=  0.96
PORT PRESS=  2113.470450
CP= -0.6
```

TABLE III (continued)

MEASURED SURFACE PRESSURES

```
 40   HZ
 65   TEMP (F)
ATMOS PRESS (PSF) 2120.016370
TUNNEL PRESS (PSF) 2115.925170
TUNNEL Q (PSF) 4.0912
TUNNEL VELOC (FPS) 58.96976976

98 PER CENT BLADES

PORT #  1
X/C=  0.352
PORT PRESS=  2113.470450
CP= -0.6

PORT #  2
X/C=  0.384
PORT PRESS=  2113.470450
CP= -0.6

PORT #  3
X/C=  0.416
PORT PRESS=  2113.470450
CP= -0.6

PORT #  4
X/C=  0.448
PORT PRESS=  2113.470450
CP= -0.6

PORT #  5
X/C=  0.48
PORT PRESS=  2113.470450
CP= -0.6

PORT #  6
X/C=  0.512
PORT PRESS=  2113.470450
CP= -0.6

PORT #  7
X/C=  0.544
PORT PRESS=  2113.470450
CP= -0.6

PORT #  8
X/C=  0.576
PORT PRESS=  2113.470450
CP= -0.6

PORT #  9
X/C=  0.608
PORT PRESS=  2113.470450
CP= -0.6

PORT #  10
X/C=  0.64
PORT PRESS=  2113.470450
CP= -0.6

PORT #  11
X/C=  0.672
PORT PRESS=  2113.061330
CP= -0.7

PORT #  12
X/C=  0.72
PORT PRESS=  2113.265890
CP= -0.65

PORT #  13
X/C=  0.736
PORT PRESS=  2113.470450
CP= -0.6

PORT #  14
X/C=  0.752
PORT PRESS=  2113.470450
CP= -0.6

PORT #  15
X/C=  0.768
PORT PRESS=  2113.470450
CP= -0.6

PORT #  16
X/C=  0.784
PORT PRESS=  2113.675010
CP= -0.55

PORT #  17
X/C=  0.8
PORT PRESS=  2113.675010
CP= -0.55

PORT #  18
X/C=  0.816
PORT PRESS=  2113.470450
CP= -0.6

PORT #  19
X/C=  0.832
PORT PRESS=  2113.470450
CP= -0.6

PORT #  20
X/C=  0.848
PORT PRESS=  2113.470450
CP= -0.6

PORT #  21
X/C=  0.864
PORT PRESS=  2113.470450
CP= -0.6

PORT #  22
X/C=  0.88
PORT PRESS=  2113.470450
CP= -0.6

PORT #  23
X/C=  0.896
PORT PRESS=  2113.470450
CP= -0.6

PORT #  24
X/C=  0.912
PORT PRESS=  2113.675010
CP= -0.55

PORT #  25
X/C=  0.928
PORT PRESS=  2113.675010
CP= -0.55

PORT #  26
X/C=  0.944
PORT PRESS=  2113.675010
CP= -0.55

PORT #  27
X/C=  0.96
PORT PRESS=  2113.675010
CP= -0.55
```

TABLE III (continued)

MEASURED SURFACE PRESSURES

```
50   HZ
65   TEMP (F)
ATMOS PRESS (PSF) 2120.016370
TUNNEL PRESS (PSF) 2115.516050
TUNNEL Q (PSF) 4.50032
TUNNEL VELOC (FPS) 61.84801630

98 PER CENT BLADES

PORT #  1
X/C=  0.352
PORT PRESS=  2110.402050
CP= -1.136363636

PORT #  2
X/C=  0.384
PORT PRESS=  2110.402050
CP= -1.136363636

PORT #  3
X/C=  0.416
PORT PRESS=  2110.606610
CP= -1.09090909

PORT #  4
X/C=  0.448
PORT PRESS=  2110.606610
CP= -1.09090909

PORT #  5
X/C=  0.48
PORT PRESS=  2110.606610
CP= -1.09090909

PORT #  6
X/C=  0.512
PORT PRESS=  2110.606610
CP= -1.09090909

PORT #  7
X/C=  0.544
PORT PRESS=  2110.606610
CP= -1.09090909

PORT #  8
X/C=  0.576
PORT PRESS=  2110.606610
CP= -1.09090909

PORT #  9
X/C=  0.608
PORT PRESS=  2110.606610
CP= -1.09090909

PORT #  10
X/C=  0.64
PORT PRESS=  2111.015730
CP= -1

PORT #  11
X/C=  0.672
PORT PRESS=  2110.402050
CP= -1.136363636

PORT #  12
X/C=  0.72
PORT PRESS=  2111.015730
CP= -1

PORT #  13
X/C=  0.736
PORT PRESS=  2111.424850
CP= -0.909090909

PORT #  14
X/C=  0.752
PORT PRESS=  2111.424850
CP= -0.909090909

PORT #  15
X/C=  0.768
PORT PRESS=  2111.833970
CP= -0.818181818

PORT #  16
X/C=  0.784
PORT PRESS=  2111.833970
CP= -0.818181818

PORT #  17
X/C=  0.8
PORT PRESS=  2112.038530
CP= -0.772727273

PORT #  18
X/C=  0.816
PORT PRESS=  2112.038530
CP= -0.772727273

PORT #  19
X/C=  0.832
PORT PRESS=  2112.243090
CP= -0.727272727

PORT #  20
X/C=  0.848
PORT PRESS=  2112.447650
CP= -0.681818182

PORT #  21
X/C=  0.864
PORT PRESS=  2112.447650
CP= -0.681818182

PORT #  22
X/C=  0.88
PORT PRESS=  2112.447650
CP= -0.681818182

PORT #  23
X/C=  0.896
PORT PRESS=  2112.652210
CP= -0.636363636

PORT #  24
X/C=  0.912
PORT PRESS=  2112.856770
CP= -0.590909091

PORT #  25
X/C=  0.928
PORT PRESS=  2113.061330
CP= -0.545454545

PORT #  26
X/C=  0.944
PORT PRESS=  2113.265890
CP= -0.5

PORT #  27
X/C=  0.96
PORT PRESS=  2113.470450
CP= -0.454545455
```

TABLE III (continued)

MEASURED SURFACE PRESSURES

```
60    HZ
65    TEMP (F)
ATMOS PRESS (PSF) 2120.016370
TUNNEL PRESS (PSF) 2117.970770
TUNNEL Q (PSF) 2.0456
TUNNEL VELOC (FPS) 41.69792408
```

98 PER CENT BLADES

PORT #	X/C=	PORT PRESS=	CP=
1	0.352	2115.925170	-1
2	0.384	2115.925170	-1
3	0.416	2115.925170	-1
4	0.448	2115.925170	-1
5	0.48	2115.925170	-1
6	0.512	2115.925170	-1
7	0.544	2115.925170	-1
8	0.576	2115.925170	-1
9	0.608	2115.925170	-1
10	0.64	2115.925170	-1
11	0.672	2115.925170	-1
12	0.72	2116.129730	-0.9
13	0.736	2116.129730	-0.9
14	0.752	2116.129730	-0.9
15	0.768	2116.334290	-0.8
16	0.784	2116.334290	-0.8
17	0.8	2116.334290	-0.8
18	0.816	2116.538850	-0.7
19	0.832	2116.538850	-0.7
20	0.848	2116.538850	-0.7
21	0.864	2116.538850	-0.7
22	0.88	2116.743410	-0.6
23	0.896	2116.743410	-0.6
24	0.912	2116.743410	-0.6
25	0.928	2116.743410	-0.6
26	0.944	2116.947970	-0.5
27	0.96	2116.947970	-0.5

TABLE III (continued)

MEASURED SURFACE PRESSURES

```
70    HZ
65    TEMP (F)
ATMOS PRESS (PSF) 2120.016370
TUNNEL PRESS (PSF) 2118.379890
TUNNEL Q (PSF) 1.63648
TUNNEL VELOC (FPS) 37.2957571

                         98 PER CENT BLADES

PORT #  1                         PORT #  10                        PORT #  19
X/C=  0.352                       X/C=  0.64                        X/C=  0.832
PORT PRESS=  2117.357090          PORT PRESS=  2117.357090          PORT PRESS=  2117.357090
CP= -0.625                        CP= -0.625                        CP= -0.625

PORT #  2                         PORT #  11                        PORT #  20
X/C=  0.384                       X/C=  0.672                       X/C=  0.848
PORT PRESS=  2117.357090          PORT PRESS=  2117.357090          PORT PRESS=  2117.357090
CP= -0.625                        CP= -0.625                        CP= -0.625

PORT #  3                         PORT #  12                        PORT #  21
X/C=  0.416                       X/C=  0.72                        X/C=  0.864
PORT PRESS=  2117.357090          PORT PRESS=  2117.357090          PORT PRESS=  2117.357090
CP= -0.625                        CP= -0.625                        CP= -0.625

PORT #  4                         PORT #  13                        PORT #  22
X/C=  0.448                       X/C=  0.736                       X/C=  0.88
PORT PRESS=  2117.357090          PORT PRESS=  2117.357090          PORT PRESS=  2117.357090
CP= -0.625                        CP= -0.625                        CP= -0.625

PORT #  5                         PORT #  14                        PORT #  23
X/C=  0.48                        X/C=  0.752                       X/C=  0.896
PORT PRESS=  2117.357090          PORT PRESS=  2117.357090          PORT PRESS=  2117.357090
CP= -0.625                        CP= -0.625                        CP= -0.625

PORT #  6                         PORT #  15                        PORT #  24
X/C=  0.512                       X/C=  0.768                       X/C=  0.912
PORT PRESS=  2117.357090          PORT PRESS=  2117.357090          PORT PRESS=  2117.561650
CP= -0.625                        CP= -0.625                        CP= -0.5

PORT #  7                         PORT #  16                        PORT #  25
X/C=  0.544                       X/C=  0.784                       X/C=  0.928
PORT PRESS=  2117.357090          PORT PRESS=  2117.357090          PORT PRESS=  2117.561650
CP= -0.625                        CP= -0.625                        CP= -0.5

PORT #  8                         PORT #  17                        PORT #  26
X/C=  0.576                       X/C=  0.8                         X/C=  0.944
PORT PRESS=  2117.357090          PORT PRESS=  2117.357090          PORT PRESS=  2117.766210
CP= -0.625                        CP= -0.625                        CP= -0.375

PORT #  9                         PORT #  18                        PORT #  27
X/C=  0.608                       X/C=  0.816                       X/C=  0.96
PORT PRESS=  2117.357090          PORT PRESS=  2117.357090          PORT PRESS=  2117.766210
CP= -0.625                        CP= -0.625                        CP= -0.375
```

TABLE IV

PRESSURE SURVEY DATA

PRIMARY MODEL

67% Shutter Blades Installed

Ambient Conditions: Temperature = 68°F, Pressure = 30.00 inches Hg

f = 0 Hz, q = 20 cm H_2O		f = 1 Hz, q = 5.0 cm H_2O	
Static Port Number	Pressure (cm H_2O)	Static Port Number	Pressure (cm H_2O)
1	37.8	1	9.3
2	36.8	2	9.1
3	35.8	3	8.8
4	35.3	4	8.7
5	34.8	5	8.6
6	34.8	6	8.6
7	34.8	7	8.6
8	33.8	8	8.3
9	35.8	9	8.8
10	36.8	10	9.0
11	39.8	11	10.0
12	35.8	12	8.8
13	34.3	13	8.3
14	32.3	14	7.8
15	29.3	15	7.4
16	28.3	16	7.2
17	25.8	17	7.0
18	24.8	18	6.8
19	23.8	19	6.5
20	23.3	20	6.2
21	22.8	21	6.2
22	22.3	22	6.0
23	21.3	23	5.9
24	20.8	24	5.8
25	20.3	25	5.6
26	20.0	26	5.5
27	19.8	27	5.4

TABLE IV (continued)

PRESSURE SURVEY DATA

PRIMARY MODEL

67% Shutter Blades Installed

Ambient Conditions: Temperature = 68°F, Pressure = 30.00 inches Hg

f = 2 Hz
q = 4.5 cm H_2O

Static Port Number	Pressure (cm H_2O)
1	8.2
2	7.9
3	7.8
4	7.6
5	7.5
6	7.5
7	7.6
8	7.3
9	7.8
10	8.0
11	8.6
12	7.8
13	7.3
14	7.0
15	6.6
16	6.3
17	6.2
18	6.0
19	5.6
20	5.4
21	5.3
22	5.2
23	5.2
24	5.1
25	5.0
26	4.9
27	4.8

f = 4 Hz
q = 3.8 cm H_2O

Static Port Number	Pressure (cm H_2O)
1	7.1
2	6.9
3	6.7
4	6.5
5	6.5
6	6.5
7	6.5
8	6.3
9	6.7
10	6.8
11	7.4
12	6.7
13	6.2
14	5.9
15	5.5
16	5.4
17	5.2
18	5.1
19	4.9
20	4.5
21	4.4
22	4.3
23	4.3
24	4.2
25	4.1
26	4.0
27	4.0

TABLE IV (continued)

PRESSURE SURVEY DATA

PRIMARY MODEL

67% Shutter Blades Installed

Ambient Conditions: Temperature = $68^\circ F$, Pressure = 30.00 inches Hg

f = 6 Hz, q = 3.8 cm H_2O		f = 25 Hz, q = 4.5 cm H_2O	
Static Port Number	Pressure (cm H_2O)	Static Port Number	Pressure (cm H_2O)
1	7.0	1	7.8
2	6.7	2	7.7
3	6.6	3	7.6
4	6.5	4	7.5
5	6.3	5	7.4
6	6.4	6	7.3
7	6.5	7	7.2
8	6.1	8	7.0
9	6.7	9	7.6
10	6.8	10	7.8
11	7.4	11	8.3
12	6.7	12	7.6
13	6.3	13	7.0
14	5.9	14	6.6
15	5.7	15	6.3
16	5.5	16	6.1
17	5.2	17	5.8
18	5.1	18	5.8
19	4.7	19	5.6
20	4.5	20	5.3
21	4.5	21	5.3
22	4.2	22	5.3
23	4.2	23	5.2
24	4.2	24	5.1
25	4.1	25	5.0
26	4.1	26	4.8
27	4.0	27	4.8

TABLE IV (continued)

PRESSURE SURVEY DATA

PRIMARY MODEL

67% Shutter Blades Installed

Ambient Conditions: Temperature = 68^{o}F, Pressure = 30.00 inches Hg

f = 30 Hz, q = 5.0 cm H_2O		f = 40 Hz, q = 4.5 cm H_2O	
Static Port Number	Pressure (cm H_2O)	Static Port Number	Pressure (cm H_2O)
1	7.8	1	6.8
2	7.6	2	6.7
3	7.4	3	6.6
4	7.3	4	6.4
5	7.3	5	6.3
6	7.3	6	6.3
7	7.3	7	6.3
8	7.1	8	6.0
9	7.8	9	6.6
10	7.8	10	6.8
11	8.8	11	7.3
12	7.8	12	6.8
13	7.0	13	6.3
14	6.8	14	5.8
15	6.6	15	5.6
16	6.4	16	5.5
17	6.0	17	5.3
18	5.8	18	5.0
19	5.6	19	4.8
20	5.3	20	4.7
21	5.3	21	4.6
22	5.2	22	4.4
23	5.2	23	4.3
24	5.1	24	4.3
25	5.1	25	4.2
26	5.0	26	4.1
27	4.8	27	4.0

TABLE IV (continued)

PRESSURE SURVEY DATA

PRIMARY MODEL

67% Shutter Blades Installed

Ambient Conditions: Temperature = 68°F, Pressure = 30.00 inches Hg

f = 50 Hz, q = 5.0 cm H_2O		f = 60 Hz, q = 3.8 cm H_2O	
Static Port Number	Pressure (cm H_2O)	Static Port Number	Pressure (cm H_2O)
1	8.3	1	6.8
2	8.1	2	6.6
3	8.0	3	6.5
4	7.8	4	6.4
5	7.6	5	6.3
6	7.6	6	6.3
7	7.6	7	6.3
8	7.2	8	6.0
9	7.8	9	6.5
10	8.0	10	6.6
11	8.6	11	7.2
12	7.6	12	6.5
13	7.1	13	6.0
14	6.8	14	5.6
15	6.3	15	5.4
16	6.2	16	5.3
17	6.0	17	5.2
18	5.8	18	4.8
19	5.4	19	4.6
20	5.3	20	4.5
21	5.2	21	4.5
22	5.1	22	4.4
23	5.0	23	4.3
24	4.8	24	4.3
25	4.6	25	4.2
26	4.5	26	4.2
27	4.4	27	4.0

TABLE IV (continued)

PRESSURE SURVEY DATA

PRIMARY MODEL

67% Shutter Blades Installed

Ambient Conditions: Temperature = 68°F, Pressure = 30.00 inches Hg

f = 70 Hz, q = 3.8 cm H_2O		f = 80 Hz, q = 5.8 cm H_2O	
Static Port Number	Pressure (cm H_2O)	Static Port Number	Pressure (cm H_2O)
1	6.8	1	7.6
2	6.6	2	7.4
3	6.3	3	7.2
4	6.2	4	7.0
5	6.2	5	7.0
6	6.2	6	7.0
7	6.2	7	7.0
8	5.8	8	6.8
9	6.4	9	7.6
10	6.6	10	7.8
11	7.0	11	8.6
12	6.4	12	8.0
13	6.0	13	7.3
14	5.6	14	7.0
15	5.4	15	6.8
16	5.2	16	6.6
17	5.0	17	6.3
18	4.8	18	6.1
19	4.6	19	5.8
20	4.4	20	5.6
21	4.4	21	5.6
22	4.4	22	5.5
23	4.3	23	5.4
24	4.2	24	5.3
25	4.2	25	5.2
26	4.1	26	5.2
27	4.0	27	5.0

TABLE IV (continued)

PRESSURE SURVEY DATA

PRIMARY MODEL

67% Shutter Blades Installed

Ambient Conditions: Temperature = 68^oF, Pressure = 30.00 inches hg

f = 90 Hz, q = 4.5 cm H_2O		f = 100 Hz, q = 3.8 cm H_2O	
Static Port Number	Pressure (cm H_2O)	Static Port Number	Pressure (cm H_2O)
1	7.0	1	6.8
2	6.8	2	6.6
3	6.6	3	6.5
4	6.5	4	6.4
5	6.3	5	6.2
6	6.4	6	6.3
7	6.4	7	6.3
8	6.2	8	6.0
9	6.8	9	6.5
10	6.8	10	6.6
11	7.4	11	7.0
12	6.6	12	6.4
13	6.1	13	5.9
14	5.8	14	5.7
15	5.6	15	5.4
16	5.4	16	5.3
17	5.2	17	5.0
18	5.0	18	4.8
19	4.8	19	4.6
20	4.6	20	4.4
21	4.6	21	4.4
22	4.4	22	4.3
23	4.4	23	4.3
24	4.4	24	4.2
25	4.3	25	4.1
26	4.2	26	4.1
27	4.0	27	4.0

TABLE IV (continued)

PRESSURE SURVEY DATA

PRIMARY MODEL

98% Shutter Blades Installed

Ambient Conditions: Temperature = 72°F, Pressure = 30.08 inches Hg

f = 1 Hz, q = 3.0 cm H_2O		f = 2 Hz, q = 2.0 cm H_2O	
Static Port Number	Pressure (cm H_2O)	Static Port Number	Pressure (cm H_2O)
1	5.0	1	4.0
2	4.9	2	3.9
3	4.8	3	3.7
4	4.5	4	3.5
5	4.5	5	3.5
6	4.5	6	3.5
7	4.5	7	3.5
8	4.4	8	3.3
9	5.0	9	3.6
10	5.0	10	3.6
11	5.3	11	4.0
12	5.0	12	3.6
13	4.5	13	3.3
14	4.3	14	3.2
15	4.0	15	3.0
16	3.9	16	2.9
17	3.5	17	2.9
18	3.7	18	2.7
19	3.5	19	2.7
20	3.3	20	2.5
21	3.3	21	2.5
22	3.3	22	2.3
23	3.2	23	2.3
24	3.1	24	2.3
25	3.0	25	2.1
26	3.0	26	2.1
27	3.0	27	2.0

TABLE IV (continued)

PRESSURE SURVEY DATA

PRIMARY MODEL

98% Shutter Blades Installed

Ambient Conditions: Temperature = 72°F, Pressure = 30.08 inches Hg

f = 4 Hz
q = 0.5 cm H_2O

Static Port Number	Pressure (cm H_2O)
1	1.3
2	1.2
3	1.1
4	1.0
5	1.0
6	1.0
7	1.0
8	1.0
9	1.0
10	1.0
11	1.0
12	0.9
13	0.7
14	0.6
15	0.6
16	0.5
17	0.5
18	0.7
19	0.5
20	0.3
21	0.3
22	0.3
23	0.2
24	0.2
25	0.2
26	0.2
27	0.1

f = 6 Hz
q = 0.5 cm H_2O

Static Port Number	Pressure (cm H_2O)
1	0.7
2	0.6
3	0.5
4	0.5
5	0.5
6	0.5
7	0.5
8	0.5
9	0.5
10	0.5
11	0.5
12	0.5
13	0.3
14	0.3
15	0.3
16	0.3
17	0.3
18	0.5
19	0.0
20	0.0
21	0.0
22	-0.1
23	-0.1
24	-0.1
25	-0.1
26	-0.2
27	-0.2

TABLE IV (continued)

PRESSURE SURVEY DATA

PRIMARY MODEL

98% Shutter Blades Installed

Ambient Conditions: Temperature = 65°F, Pressure = 30.06 inches Hg

f = 25 Hz, q = 1.0 cm H_2O		f = 30 Hz, q = 2.0 cm H_2O	
Static Port Number	Pressure (cm H_2O)	Static Port Number	Pressure (cm H_2O)
1	1.5	1	1.5
2	1.5	2	1.5
3	1.5	3	1.5
4	1.5	4	1.5
5	1.5	5	1.5
6	1.5	6	1.5
7	1.5	7	1.5
8	1.5	8	1.5
9	1.5	9	1.5
10	1.5	10	1.5
11	2.0	11	1.5
12	1.6	12	1.5
13	1.5	13	1.4
14	1.4	14	1.4
15	1.2	15	1.4
16	1.2	16	1.3
17	1.2	17	1.3
18	1.2	18	1.3
19	1.2	19	1.3
20	1.0	20	1.2
21	1.0	21	1.2
22	1.0	22	1.2
23	0.9	23	1.2
24	0.9	24	1.2
25	0.9	25	1.2
26	0.9	26	1.2
27	0.8	27	1.2

TABLE IV (continued)

PRESSURE SURVEY DATA

PRIMARY MODEL

98% Shutter Blades Installed

Ambient Conditions: Temperature = 65°F, Pressure = 30.06 inches Hg

f = 40 Hz, q = 2.0 cm H_2O		f = 50 Hz, q = 2.2 cm H_2O	
Static Port Number	Pressure (cm H_2O)	Static Port Number	Pressure (cm H_2O)
1	1.2	1	2.5
2	1.2	2	2.5
3	1.2	3	2.4
4	1.2	4	2.4
5	1.2	5	2.4
6	1.2	6	2.4
7	1.2	7	2.4
8	1.2	8	2.4
9	1.2	9	2.4
10	1.2	10	2.2
11	1.4	11	2.5
12	1.3	12	2.2
13	1.2	13	2.0
14	1.2	14	2.0
15	1.2	15	1.8
16	1.1	16	1.8
17	1.1	17	1.7
18	1.2	18	1.7
19	1.2	19	1.6
20	1.2	20	1.5
21	1.2	21	1.5
22	1.2	22	1.5
23	1.2	23	1.4
24	1.1	24	1.3
25	1.1	25	1.2
26	1.1	26	1.1
27	1.1	27	1.0

TABLE IV (continued)

PRESSURE SURVEY DATA

PRIMARY MODEL

98% Shutter Blades Installed

Ambient Conditions: Temperature 65°F, Pressure 30.06 inches Hg

f = 60 Hz, q = 1.0 cm H_2O		f = 70 Hz, q = 0.8 cm H_2O	
Static Port Number	Pressure (cm H_2O)	Static Port Number	Pressure (cm H_2O)
1	1.0	1	0.5
2	1.0	2	0.5
3	1.0	3	0.5
4	1.0	4	0.5
5	1.0	5	0.5
6	1.0	6	0.5
7	1.0	7	0.5
8	1.0	8	0.5
9	1.0	9	0.5
10	1.0	10	0.5
11	1.0	11	0.5
12	0.9	12	0.5
13	0.9	13	0.5
14	0.9	14	0.5
15	0.8	15	0.5
16	0.8	16	0.5
17	0.8	17	0.5
18	0.7	18	0.5
19	0.7	19	0.5
20	0.7	20	0.5
21	0.7	21	0.5
22	0.6	22	0.5
23	0.6	23	0.5
24	0.6	24	0.4
25	0.6	25	0.4
26	0.5	26	0.3
27	0.5	27	0.3

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